



INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification ⁶ : A61K 38/16, 39/395, 48/00, C07H 21/04, C12N 15/11, C12Q 1/68, G01N 33/53, C12Q 1/25, 1/66, 1/68	A1	(11) International Publication Number: WO 97/47316 (43) International Publication Date: 18 December 1997 (18.12.97)
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(21) International Application Number: PCT/US97/09969 (22) International Filing Date: 9 June 1997 (09.06.97) (30) Priority Data: 08/662,560 10 June 1996 (10.06.96) US 08/780,749 8 January 1997 (08.01.97) US Not furnished 6 June 1997 (06.06.97) US (71) Applicant: MILLENNIUM PHARMACEUTICALS, INC. [US/US]; 640 Memorial Drive, Cambridge, MA 02139 (US). (72) Inventors: LEE, Frank; 6 Norfolk Road, Chestnut Hill, MA 02160 (US). HUSZAR, Dennis; 4 Agawam Road, Acton, MA 01720 (US). GU, Wei; 1080 Beacon Street, Brookline, MA 02146 (US). (74) Agents: CORUZZI, Laura, A. et al.; Pennie & Edmonds LLP, 1155 Avenue of the Americas, New York, NY 10036 (US).	(81) Designated States: AL, AM, AU, AZ, BA, BB, BG, BR, BY, CA, CN, CU, CZ, EE, GE, GH, HU, IL, IS, JP, KG, KP, KR, KZ, LC, LK, LR, LT, LV, MD, MG, MK, MN, MX, NO, NZ, PL, RO, RU, SG, SI, SK, TJ, TM, TR, TT, UA, UZ, VN, YU, ARIPO patent (GH, KE, LS, MW, SD, SZ, UG), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).
	Published With international search report.

(54) Title: SCREENING METHODS FOR COMPOUNDS USEFUL IN THE REGULATION OF BODY WEIGHT

(57) Abstract

The present invention relates to drug screening assays, and diagnostic and therapeutic methods for the treatment of body weight disorders, such as obesity, anorexia and cachexia, utilizing the melanocortin 4-receptor (MC4-R) as the target for intervention. The invention also relates to compounds that modulate the activity or expression of the MC4-R, and the use of such compounds in the treatment of body weight disorders.

ECB 1 50
HC3 H30KMYLDO DFTVVSSES FTATLLEPOL OSALATANA SOCLPVOPT
HC4 H30KMYLDO DFTVVSSES FTATLLEPOL OSALATANA SOCLPVOPT
HC2 (ACTH) H30KMYLDO DFTVVSSES FTATLLEPOL OSALATANA SOCLPVOPT
HC1 (G-MSH) H30KMYLDO DFTVVSSES FTATLLEPOL OSALATANA SOCLPVOPT
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HC3 LPHGSEHQA PFFHOSSEA PCDVTFKPE IPLSGLIVEL LEMIVILAV
HC4 LPHGSEHQA PFFHOSSEA PCDVTFKPE IPLSGLIVEL LEMIVILAV
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HC3 VUHQHNSM YFFICSLAVA DQNSVNSAL ETTNATVNS DYLATDQPI
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HC3 QHQHNFIDEN ICSSINASIC HLLAIAVDY VTFPVALYN SIVTVERAL
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201 IV ECB 3 V 250
HC3 LTVAINWCCO VGVVTFVVS ESNVTVCLL THTNANLAN GYLIVDFLP
HC4 LTVAINWCCO VGVVTFVVS ESNVTVCLL THTNANLAN GYLIVDFLP
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HC1 (G-MSH) LTVAINWCCO VGVVTFVVS ESNVTVCLL THTNANLAN GYLIVDFLP
251 OD 3 31 VI 300
HC3 ARHAKKILAA LPPADVOAPQ QNSCKDAVT ITHAGVTFP CHAFFILEV
HC4 ARHAKKILAA LPPADVOAPQ QNSCKDAVT ITHAGVTFP CHAFFILEV
HC2 (ACTH) ARHAKKILAA LPPADVOAPQ QNSCKDAVT ITHAGVTFP CHAFFILEV
HC1 (G-MSH) ARHAKKILAA LPPADVOAPQ QNSCKDAVT ITHAGVTFP CHAFFILEV
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HC4 LIITCPHNY CICTANPNT TIALINMNEV IDPLIVAFS LEANTFREI
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HC1 (G-MSH) LIITCPHNY CICTANPNT TIALINMNEV IDPLIVAFS LEANTFREI
351
HC3 LCOCHNHLQ
HC4 LCOCHNHLQ
HC2 (ACTH) LCOCHNHLQ
HC1 (G-MSH) LCOCHNHLQ

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SCREENING METHODS FOR COMPOUNDS
USEFUL IN THE REGULATION OF BODY WEIGHT

1. INTRODUCTION

5 The present invention relates to drug screening assays,
and diagnostic and therapeutic methods for the treatment of
body weight disorders, such as obesity, anorexia and
cachexia, involving the melanocortin 4-receptor (MC4-R). The
invention also relates to compounds that modulate the
10 activity or expression of the MC4-R, and the use of such
compounds in the treatment of body weight disorders.

2. BACKGROUND OF THE INVENTION

Melanocortins (a variety of different peptide products
15 resulting from post-translational processing of
pro-opiomelanocortin) are known to have a broad array of
physiological actions. Aside from their well known effects
on adrenal cortical function (e.g., by ACTH,
adrenocorticotrophic hormone), and on melanocytes (e.g., by
20 α -MSH, melanocyte stimulating hormone), melanocortins have
been shown to affect behavior, learning, and memory, control
of the cardiovascular system, analgesia, thermoregulation,
and the release of other neurohumoral agents including
prolactin, luteinizing hormone, and biogenic amines.
25 Peripherally, melanocortins have been identified to have
immunomodulatory and neurotrophic properties and to be
involved in events surrounding parturition.

The melanocortins mediate their effects through
melanocortin receptors (MC-R) -- a subfamily of G-protein
30 coupled receptors. Other than the MC1-R which was identified
as specific for α -MSH, and MC2-R which was identified as
specific for ACTH, the melanocortin receptors cloned and
identified to date (MC3-R, MC4-R, MC5-R) are thought of as
"orphan" receptors -- i.e., the identity of the native ligand
35 for each receptor remains unidentified, and the physiologic
function of each receptor type remains unknown.

The agouti protein is a gene product expressed in mice that is known to be involved in determining coat color, but also thought to play a role in obesity when its normal expression pattern is de-regulated and the protein is ubiquitously expressed. The receptor for agouti has not been identified or cloned; however, it has been observed that agouti antagonizes the MSH-induced activation of two melanocortin receptors.

10

2.1. THE MELANOCORTIN RECEPTORS

The first two melanocortin receptors cloned were the melanocyte MSH receptor, MC1-R, and the adrenocortical ACTH receptor, MC2-R (Mountjoy et al., 1992, Science 257:1248-1251; Chhajlani & Wikberg, 1992, FEBS Lett. 309:417-420). Subsequently, three additional melanocortin receptor genes were cloned which recognize the core heptapeptide sequence (MEHFRWG) of melanocortins. Two of these receptors have been shown to be expressed primarily in the brain, MC3-R (Roselli-Reh fuss et al., 1993, Proc. Natl. Acad. Sci. USA 90:8856-8860; Gantz et al., 1993, J. Biol. Chem. 268:8246-8250) and MC4-R (Gantz et al., 1993, J. Biol. Chem. 268:15174-15179; Mountjoy et al., 1994, Mol. Endo. 8:1298-1308). A fifth melanocortin receptor (originally called MC2-R) is expressed in numerous peripheral organs as well as the brain (Chhajlani et al., 1993, Biochem. Biophys. Res. Commun. 195:866-873; Gantz et al., 1994, Biochem. Biophys. Res. Commun. 200:1214-1220). The native ligands and functions of these latter three receptors remain unknown.

Because of their "orphan" status as receptors without an identified ligand, and the absence of any known physiological role for these new receptors, investigators have attempted to characterize the receptors in vitro, by their ability to bind and respond (e.g., transduce signal) to a variety of known melanocortins (e.g., see Roselli-Reh fuss, 1993, supra; and Gantz, 1993 supra) or agonists and antagonists derived from MSH and ACTH amino acid sequences (e.g., see Hruby et al., 1995, J. Med. Chem. 38:3454-3461; and Adan et al., 1994, Eur.

J. Pharmacol. 269:331-337). In another approach, the members of the melanocortin receptor family were differentiated on the basis of their pattern of tissue distribution as a means for hypothesizing a function (e.g., See Gantz, 1993, supra; 5 and Mountjoy 1994, supra). For example, expression of MC1-R is localized to melanocytes, MC2-R is localized to adrenal cortical cells, whereas the MC3-R and MC4-R are found primarily in the brain but not in the adrenal cortex or melanocytes; MC4-R is not expressed in the placenta, a tissue 10 that expresses large amounts of MC3-R. Based upon its expression pattern in the hippocampal region of the brain, a role for the MC4-R in learning and memory was proposed (Gantz, 1993, supra) but was noted to be a "pharmacological paradox" in that the MC4-R does not respond well to compounds 15 known to have an effect on retention of learned behaviors. (Mountjoy, 1994, supra). Mountjoy 1994 further suggests that the MC4-R may participate in modulating the flow of visual and sensory information, or coordinate aspects of somatomotor control, and/or may participate in the modulation of 20 autonomic outflow to the heart.

Thus, despite such efforts, the native ligands and function of MC3-R, MC4-R and MC5-R remain elusive.

2.2. THE AGOUTI PROTEIN

25 The agouti gene is predicted to encode a secreted protein expressed in hair follicles and the epidermis, the expression of which correlates with the synthesis of the yellow pigment associated with the agouti phenotype (Miller et al., 1993, Gene & Development 7:454-467). Certain 30 dominant mutations of the agouti gene result in de-regulated, ubiquitous expression of the agouti protein in mice, demonstrating pleiotropic effects that include obesity and increased tumor susceptibility. (Miller et al., 1993, supra; Michaud et al., 1993, Genes & Development 7:1203-1213). 35 Ectopic expression of the normal, wild-type, agouti protein in transgenic mice results in obesity, diabetes, and the yellow coat color commonly observed in spontaneous obese

mutants (Klebig, et al., 1995, Proc. Natl. Acad. Sci. USA 92:4728-4732). For reviews, see Jackson, 1993, Nature 362:587-588; Conklin & Bourne, 1993, Nature 364:110; Siracusa 1994, TIG 10:423-428; Yen et al., 1994, FASEB J. 8:479-488; 5 Ezzell, 1994, J. NIH Res. 6:31-33; and Manne et al., 1995, Proc. Sci. USA 92:4721-4724.

No receptor for agouti has been identified. Agouti has been reported to be a competitive antagonist of α MSH binding to the MC1-R and MC4-R in vitro (Lu et al., 1994, Nature 10 371:799-802), and the authors speculated that ectopic expression of agouti may lead to obesity by antagonism of melanocortin receptors expressed outside the hair follicle. In this regard, a number of theories have been proposed to account for the induction of obesity by ectopic expression of 15 agouti. For example, agouti expression in skeletal muscle may result in insulin resistance, hyperinsulinemia and obesity via elevation of Ca^{2+} levels; alternatively ectopic agouti expression in adipocytes may depress lipolysis; conversely direct effects of agouti on pancreatic β islet 20 cells may result in hyperinsulinemia and obesity; yet another possibility is that agouti expression in the brain may result in obesity due to a primary effect on areas of the brain controlling weight regulation and insulin production (see Klebig 1995, supra).

25 In sum, the mechanism of agouti-induced obesity in mice is unknown, and the relevance, if any, of this phenomenon to human obese phenotypes has not been established.

3. SUMMARY OF THE INVENTION

30 The present invention relates to drug screening assays to identify compounds for the treatment of body weight disorders, such as obesity, anorexia and cachexia by using MC4-R as a target. The invention also relates to compounds that modulate body weight via the MC4-R. The present 35 invention also relates to the treatment of body weight disorders by targeting the MC4-R.

The invention is based, in part, on the discovery of a specific role for MC4-R in body weight regulation. As demonstrated herein, mice completely lacking MC4-R develop a maturity onset obesity syndrome associated with hyperphagia, hyperinsulinemia, and hyperglycemia. In particular, knock-out mice in which the gene encoding MC4-R is defective exhibit significant weight gain compared to either MC4-R heterozygous or wild-type female littermates. The invention is also based, in part, on the discovery that the agouti protein, known to be involved in an obese phenotype when ectopically expressed in mice, binds to the MC4-R.

The invention is further based in part, on the discovery that mutations in the MC4-R have been found to exist in extreme obese human patients. A comparison of the signaling response of the wild type and mutant receptors indicates impaired signaling of the mutant receptor as measured by cAMP induction in the presence of various agonists.

The invention relates to assays designed to screen for compounds or compositions that modulate MC4-R activity, i.e., compounds or compositions that act as agonists or antagonists of MC4-R, and thereby modulate weight control. To this end, cell-based assays or non-cell based assays can be used to detect compounds that interact with, e.g., bind to, a MC4-R extracellular domain ("ECD"). The cell-based assays have the advantage in that they can be used to identify compounds that affect MC4-R biological activity (i.e., signal transduction), including the identification of compounds that do not interact with a MC4-R ECD, but act on an intracellular component of the signal transduction pathway mediated by MC4-R.

The invention also relates to assays designed to screen for compounds or compositions that modulate MC4-r gene expression. For example, cell-based assays, or cell-lysate assays (e.g., in vitro transcription or translation assays) can be used to screen for compounds or compositions that modulate MC4-r transcription (e.g., compounds that modulate expression, production or activity of transcription factors

involved in MC4-r gene expression; polynucleotides that form triple helical structures with an MC4-r regulatory region and inhibit transcription of the MC4-r gene, etc.).

Alternatively, cell-based assays or cell-lysate assays can be used to screen for compounds or compositions that modulate translation of MC4-R transcripts (e.g., antisense and ribozyme molecules).

In yet another embodiment, the cell-based assays or cell-lysate assays can be used to test polynucleotide constructs designed to modify the expression of the MC4-r gene in vivo. Such constructs include polynucleotide constructs designed for gene therapy; e.g., expression constructs or gene replacement constructs that place the MC4-r gene under the control of a strong promoter system, an inducible promoter system or a constitutive promoter system.

The invention also encompasses agonists and antagonists of MC4-R, including small molecules, large molecules, and antibodies, as well as nucleotide sequences that can be used to inhibit MC4-r gene expression (e.g., antisense and ribozyme molecules), and gene or regulatory sequence replacement constructs designed to enhance MC4-r gene expression (e.g., expression constructs that place the MC4-r gene under the control of a strong promoter system). Such compounds may be used to treat body weight disorders.

In addition, this invention presents methods for the diagnostic evaluation and prognosis of body weight disorders, including obesity, cachexia and anorexia, and for the identification of subjects having a predisposition to such conditions. For example, nucleic acid molecules encoding MC4-R can be used as diagnostic hybridization probes or as primers for diagnostic PCR analysis for the identification of MC4-R gene mutations, allelic variations and regulatory defects in the MC4-R gene based in part on the identification of MC4-R mutants in human obese patients.

The invention also encompasses the use of such compounds and compositions, including gene therapy approaches, that

modulate MC4-R activity or MC4-r gene expression to treat body weight disorders.

3.1. DEFINITIONS

5 The following terms as used herein shall have the meaning indicated.

MC4-r nucleotides or coding sequences: means DNA sequences encoding MC4-R mRNA transcripts, MC4-R protein, polypeptide or peptide fragments of MC4-R protein, or MC4-R
10 fusion proteins. MC4-r nucleotide sequences encompass DNA, including genomic DNA (e.g. the MC4-r gene) or cDNA.

MC4-R means MC4-r gene products, e.g., transcripts and the MC4 receptor protein. Polypeptides or peptide fragments of the MC4-R protein are referred to as MC4-R polypeptides or
15 MC4-R peptides. Fusions of MC4-R, or MC4-R polypeptides, or peptide fragments to an unrelated protein are referred to herein as MC4-R fusion proteins. A functional MC4-R refers to a protein which binds melanocortin peptides in vivo or in vitro.

20 ECD: means "extracellular domain".

TM: means "transmembrane domain".

CD: means "cytoplasmic domain".

4. DESCRIPTION OF THE FIGURES

25 FIG. 1. Deduced amino acid sequences of the melanocortin receptors. The serpentine structure of the melanocortin receptors predicts that the hydrophilic domains located between the TM domains are arranged alternately outside and within the cell to form the ECD (amino acid residues 1-74,
30 137-155, 219-231 and 305-316 in FIG. 1) and the CD (amino acid residues 102-112, 178-197, 251-280 and 339-end in FIG. 1) of the receptor. The predicted transmembrane domains are denoted by overbars and Roman numerals, and the four extracellular domains (ECD1, ECD2, ECD3 and ECD4) and four
35 cytoplasmic domains (CD1, CD2, CD3 and CD4) are indicated.

FIG. 2. Schematic diagram of the construction of the MC4-R targeting vector. FIG. 2A. Partial restriction map of the MC4-R locus. FIG. 2B. The MC4 KO 5' construct, containing genomic sequences from 3' of the MC4-R gene in the vector pJN2. FIG. 2C. The MC4-R KO 5'3' construct in which genomic sequences from 5' of the MC4-R gene have been inserted into the MC4 KO 5' construct. FIG. 2D. The MC4-R KO 5'3' neo construct in which a neo expression cassette has been inserted between the 5' and 3' flanking sequences of the MC4-R gene. The dotted line represents the pJN2 vector. The open box represents the PGK-neo expression cassette, the hatched box represents the MC4-R gene and the arrows indicate the direction of transcription.

FIG. 3 Schematic diagram of the gene targeting strategy for inactivation of the MC4-R. FIG. 3A. Diagram of the MC4-R locus. The hatched box represents MC4-R coding sequences, the solid box indicates the location of the SacI-SphI probe used for identifying homologous recombinants. The arrow indicates the direction of transcription of the MC4-R gene. FIG. 3B. Diagram of the MC4-R targeting construct. The dashed line represents pJN2 plasmid sequences and the arrow indicates the direction of neo transcription. FIG. 3C. Diagram of the MC4-R locus following homologous recombination with the targeting vector. FIG. 3D. Predicted restriction fragment lengths for the wild type and mutated MC4-R loci digested with the indicated enzymes and probed with the SacI-SphI probe. FIG. 3E. Autoradiogram of a Southern blot analysis of tail DNA from F2 progeny. Genomic DNA was digested with ApaI or NcoI, as indicated and hybridized with the radiolabeled probe shown in (A), then stripped and rehybridized with a radiolabeled probe consisting of the human MC4-R coding sequence. +/+, +/-, and -/- denote DNA from wild-type, heterozygous, and homozygous F2 littermates, respectively.

FIG. 4 Weight gain of MC4-R deficient mice and control littermates. Each line represents the weight gain of an individual mouse. FIG. 4A. Weight gain of female homozygous (-/-) mutant mice (closed squares) and wild type (+/+) F2 controls (open circles). The weights of 9 homozygous and 12 control mice were taken at the times indicated. FIG. 4B. Weight gain of female heterozygous (+/-) mutant mice (x) and wild type (+/+) F2 controls (open circles). The weights of 18 heterozygous and 12 control mice were taken at the times indicated. FIG. 4C. Weight gain of male homozygous (-/-) mutant mice (closed squares) and wild-type (+/+) F2 controls (open circles). The weights of 9 homozygous and 17 control mice were taken at the times indicated. FIG. 4D. Weight gain of male heterozygous (+/-) mutant mice (x) and wild-type (+/+) F2 controls (open circles). The weights of 18 heterozygous and 17 control mice were taken at the times indicated.

FIG. 5 Sequence of the human MC4-R. Transmembrane domains are underlined. Amino acid differences in the rat MC4-R are indicated underneath the human sequence.

FIG. 6 Increased linear growth of MC4-R deficient mice. The body length of female (open bars) and male (cross-hatched bars) was measured at approximately 19 weeks of age (between 132-138 days). The bars indicate the mean length of 12 wild type (+/+), and 9 homozygous mutant (-/-) female F2 mice, and 15 wild type, 20 heterozygous, and 9 homozygous mutant male F2 mice. Error bars represent the standard error of the mean, and the asterisks denote significant difference ($p < 0.02$ by two tailed Student t test) compared to the wild type value within a similar sex.

FIG. 7 Mice lacking the MC4-R are hyperphagic. The food intake of female mice housed in pairs was measured every weekday over a two week period. The open bars represent the mean of 8 measurements on one cage each of two Ay and two

control C57BL/6 mice. The hatched bars represent the mean of 8 measurements on each of two cages of two homozygous mutant mice (-/-) and two F2 wild type controls (+/+). Error bars represent the standard error of the mean, and the asterisks denote significant difference ($p < 0.01$ by two tailed Student t test) of either Ay compared to C57BL/6 or MC4-R (-/-) homozygous mutants compared to MC4-R (+/+) wild type F2 mice.

FIG. 8. Serum glucose, insulin, and leptin levels in mice lacking the MC4-R. Glucose, insulin and leptin were each measured on the same serum samples. Open bars represent heterozygotes, and shaded bars represent homozygous mutant mice. Error bars indicate the standard error of the mean. Asterisks denote significant difference ($p < 0.05$ by two-tailed student t test) compared to control within the same sex and age group. For female mice, the n for wild type mice at 4-8 weeks, 10-14 weeks, and 17-23 weeks was 11, 14, and 7, respectively; and for homozygous mutants, 7, 11 and 3, respectively. For male mice, the n for wild-type mice at 4-8 weeks, 10-14 weeks and 17-23 weeks was 14, 14, and 6, respectively; and for homozygous mutants, 8, 8, and 9, respectively. FIG. 8A and 8B. Serum glucose levels of female and male mice, respectively. Five μ l of serum was analyzed using a glucose oxidase assay. FIG. 8C and 8D. Serum insulin levels of female and male mice, respectively, were assayed by radioimmunoassay using rat insulin as the standard. FIG. 8E and 8F. Serum leptin levels of female and male mice, respectively, were measured by radioimmunoassay.

FIG. 9. MC4-R gene deletion does not affect basal serum corticosterone. Serum corticosterone levels were measured in three sets of sex matched littermates containing a representative animal of each genotype: +/+ wild-type control, +/- heterozygote, -/-homozygous mutant. Sets are, from left to right, male, female, and male. Males were 15 weeks of age, females were 18 weeks of age. Data indicate the means of measurements performed using two serum samples obtained on

different days. Measurement on each day was performed in duplicate. Bars indicate standard deviation. Analysis of data by two-way ANOVA indicated no significant difference in corticosterone levels as a function of genotype.

5

FIG. 10. MC4-R gene deletion does not effect brain POMC mRNA levels. FIG. 10A, 10B and 10C. Hematoxylin and eosin stained brain sections from wild type, heterozygous, and homozygous mutant MC4-R deficient mice, respectively. FIG.

10 10D, 10E and 10F. Autoradiographs of brain sections from wild type, heterozygous, and homozygous mutant MC4-R deficient mice, respectively, hybridized with a ³⁵S-POMC antisense cRNA probe.

15 FIG. 11A-11B. Sequence of mutant MC4-R. Mutation is Ile137Thr (T to C) mutation.

FIG. 12A-12B. Sequence of mutant MC4-R. Mutation is Val102Ile (G to A) mutation.

20

FIG. 13A-13B. Sequence of mutant MC4-R. Mutation is Thr112Met (C to T) mutation.

FIG. 14. Impaired Signaling of the I137T mutant receptor.

25 The signaling response of the wild type (wt) and mutant (mt) receptor to five endogenous melanocortins, α -MSH (alpha), β -MSH (beta), γ 1-MSH 9 (gamma1), γ 2-MSH (gamma2) and ACTH was compared.

30

5. DETAILED DESCRIPTION OF THE INVENTION

The invention described in the subsections below encompasses screening methods (e.g., assays) for the identification of compounds which affect weight modulation. The invention also encompasses agonists and antagonists of
35 MC4-R, including small molecules, large molecules, and antibodies, as well as nucleotide sequences that can be used to inhibit MC4-r gene expression (e.g., antisense and

ribozyme molecules), and gene or regulatory sequence replacement constructs designed to enhance MC4-r gene expression (e.g., expression constructs that place the MC4-r gene under the control of a strong promoter system). Such 5 compounds may be used to treat body weight disorders.

In particular, cellular and non-cellular assays are described that can be used to identify compounds that interact with the MC4-R, e.g., modulate the activity of the MC4-R and/or bind to the MC4-R. The cell based assays can be 10 used to identify compounds or compositions that affect the signal-transduction activity of the MC4-R, whether they bind to the MC4-R or act on intracellular factors involved in the MC4-R signal transduction pathway. Such cell-based assays of the invention utilize cells, cell lines, or engineered cells 15 or cell lines that express the MC4-R. The cells can be further engineered to incorporate a reporter molecule linked to the signal transduced by the activated MC4-R to aid in the identification of compounds that modulate MC4-R signalling activity.

20 The invention also encompasses the use of cell-based assays or cell-lysate assays (e.g., in vitro transcription or translation assays) to screen for compounds or compositions that modulate MC4-r gene expression. To this end, constructs containing a reporter sequence linked to a regulatory element 25 of the MC4-r gene can be used in engineered cells, or in cell lysate extracts, to screen for compounds that modulate the expression of the reporter gene product at the level of transcription. For example, such assays could be used to identify compounds that modulate the expression or activity 30 of transcription factors involved in MC4-r gene expression, or to test the activity of triple helix polynucleotides. Alternatively, engineered cells or translation extracts can be used to screen for compounds (including antisense and ribozyme constructs) that modulate the translation of MC4-R 35 mRNA transcripts, and therefore, affect expression of the MC4-R.

The invention also encompasses MC4-R proteins, polypeptides (including soluble MC4-R polypeptides or peptides) and MC4-R fusion proteins for use in non-cell based screening assays, for use in generating antibodies, for
5 diagnostics and therapeutics. The MC4-R is predicted to be a serpentine receptor that traverses the membrane seven times, resulting in four extra-cellular domains (ECDs) and four cellular domains (CDs) (see FIG. 1). Peptides corresponding to each ECD, or a polypeptide composed of two or more of the
10 four ECDs linked together can be engineered as described in Section 5.3.1, infra. Alternatively, such peptides or polypeptides can be fused to a heterologous protein, e.g., a reporter, an Ig Fc region, etc., to yield a fusion protein. Such peptides, polypeptides and fusion proteins can be used
15 in the non-cell based assays for screening compounds that interact with, e.g., modulate the activity of the MC4-R and or bind to the MC4-R.

MC4-R protein products can be used to treat weight disorders such as obesity, anorexia or cachexia. Such MC4-R
20 protein products include but are not limited to soluble derivatives such as peptides or polypeptides corresponding to one or more MC4-R ECDs; truncated MC4-R polypeptides lacking one or more ECD or TM; and MC4-R fusion protein products (especially MC4-R-Ig fusion proteins, i.e., fusions of the
25 MC4-R or a domain of the MC4-R, to an IgFc domain).

Alternatively, antibodies to the MC4-R or anti-idiotypic antibodies that mimic the MC4-R (including Fab fragments), antagonists or agonists (including compounds that modulate signal transduction which may act on downstream targets in
30 the MC4-R signal transduction pathway) can be used to treat body weight disorders such as obesity, anorexia or cachexia.

For example, the administration of an effective amount of soluble MC4-R polypeptide, or an MC4-R fusion protein (e.g., MC4-R ECD-IgFc) or an anti-idiotypic antibody (or its
35 Fab) that mimics the MC4-R ECD would interact with and thereby "mop up" or "neutralize" endogenous MC4-R ligand, and prevent or reduce binding and receptor activation, leading to

weight gain. In yet another approach, nucleotide constructs encoding such MC4-R products can be used to genetically engineer host cells to express such MC4-R products in vivo; these genetically engineered cells can function as

5 "bioreactors" in the body delivering a continuous supply of the MC4-R, MC4-R peptide, soluble MC4-R polypeptide, or MC4-R fusion protein that will "mop up" or neutralize MC4-R ligand.

"Gene therapy" approaches for the modulation of MC4-R expression and/or activity in the treatment of body weight
10 disorders are within the scope of the invention. For example, nucleotide constructs encoding functional MC4-Rs, mutant MC4-Rs, as well as antisense and ribozyme molecules can be used to modulate MC4-r expression.

The invention also encompasses pharmaceutical
15 formulations and methods for treating body weight disorders.

5.1. THE ROLE OF MC4-R IN THE REGULATION OF BODY WEIGHT

The specific role of the MC4-R protein in vivo was
20 investigated by engineering MC4-R "knock out" mice in which most of the endogenous MC4-R gene coding sequence was deleted, thereby creating mice which are unable to produce functional MC4-R protein. Unlike MC-R agonist/antagonist studies which are complicated because each of the MC
25 receptors, rather than just MC4-R, can be affected, this specific elimination of only MC4-R function allowed an evaluation of the biological function of MC4-R.

In order to produce the MC4-R knock out mice, human MC4-r gene sequences were utilized to isolate and clone the
30 murine MC4-r gene. A murine MC4-r targeting construct was then generated which was designed to delete the majority of the murine MC4-r coding sequence upon homologous recombination with the endogenous murine MC4-r gene. Embryonic stem (ES) cells containing the disrupted MC4-r gene
35 were produced, isolated and microinjected into murine blastocysts to yield mice chimeric for cells containing a disrupted MC4-r gene. Offspring of the chimeric mice

resulting from germline transmission of the ES genome were obtained and animals heterozygous for the disrupted MC4-R were identified.

In order to assess the role of MC4-R in vivo, the animals heterozygous for the MC4-r disrupted gene were bred together, producing litters containing wild-type mice, mice heterozygous for the MC4-r mutation and mice homozygous for the MC4-R mutation. Inactivation of the MC4-R by gene targeting results in mice that develop a maturity onset obesity syndrome associated with hyperphagia, hyperinsulinemia, and hyperglycemia.

The weight gain of the animals was monitored regularly. Homozygous null MC4-R mutants showed an increase in weight compared to mice heterozygous for MC4-R deletion and wild type mice as early as 25 days of age. By approximately 5 weeks of age, most of the homozygous mutants, both males and females, were heavier than their wild type siblings of the same sex, and by 7 weeks of age all of the null mutants were heavier than the controls (FIG. 4A and 4C). By 15 weeks of age, homozygous mutant females were on average twice as heavy as their wild-type siblings, while homozygous mutant males were approximately 50% heavier than wild-type controls. Mice heterozygous for MC4-R deletion showed a weight gain intermediate to that seen in wild-type and homozygous mutant siblings (FIG. 4B and 4D), demonstrating a gene dosage effect of MC4-R ablation on body weight regulation.

In addition, as demonstrated in FIG. 6, MC4-R deficient mice are significantly longer than wild-type controls. The mean length of homozygous mutant females is increased approximately 11% relative to wild-type F2 mice, and heterozygous females are approximately 7% longer than controls. Male homozygotes and heterozygotes are approximately 8% and 2.5% longer than controls, respectively. Absence of the MC4-R also resulted in a significant increase (46%) in food consumption over wild-type F2 controls.

Blood was collected from MC4-R deficient mice and assayed for serum levels of glucose, insulin and leptin

concentrations. Serum glucose levels were essentially unchanged in females heterozygous or homozygous for MC4-R deletion, but both heterozygous and homozygous males were hyperglycemic (FIG. 8A and 8B). Both male and female mice were also found to be hyperinsulinemic (FIG. 8C and 8D). Heterozygous mutants were hyperinsulinemic, although less so than homozygous mutants. In addition to glucose and insulin, serum leptin levels were altered in MC4-R deficient mice (FIG. 8R and 8F). Heterozygous mice, for the most part, showed leptin levels intermediate between that observed for wild-type mice and homozygous mutants.

The knock out experiments described herein represent definitive evidence of the role of MC4-R in weight regulation. The experimental design does not rely on the relationship, if any, of the agouti ligand for the characterization of the functional role of the MC4-R.

In addition, the role of MC4-R in weight regulation is demonstrated by the discovery of mutant forms of MC4-R variants in obese human patients. A comparison of the signaling response of the wild type and mutant receptors indicate impaired signaling of the mutant receptor as measured by cAMP induction in the presence of various agonists. Compared with the wildtype receptor, the mutant has much lower maximum activation, i.e., lower maximum cAMP level achieved; and it generally has higher EC50, i.e., higher agonist concentration required to reach half maximum activation. The mutant receptor is only marginally active in the presence of very high agonist concentration that may not be reached under physiological conditions in vivo.

30

5.2. SCREENING ASSAYS FOR DRUGS USEFUL IN REGULATION OF BODY WEIGHT

At least three different assay systems, described in the subsections below, can be designed and used to identify compounds or compositions that modulate MC4-R activity or MC4-r gene expression, and therefore, modulate weight control.

35

The systems described below may be formulated into kits. To this end, the MC4-R or cells expressing the MC4-R can be packaged in a variety of containers, e.g., vials, tubes, microtitre well plates, bottles, and the like. Other
5 reagents can be included in separate containers and provided with the kit; e.g., positive controls samples, negative control samples, melanocortin peptides (including but not limited to α MSH and ACTH derivatives), buffers, cell culture media, etc.

10

5.2.1. CELL-BASED ASSAYS

In accordance with the invention, a cell-based assay system can be used to screen for compounds that modulate the activity of the MC4-R and thereby, modulate body weight. To
15 this end, cells that endogenously express MC4-R can be used to screen for compounds. Alternatively, cell lines, such as 293 cells, COS cells, CHO cells, fibroblasts, and the like, genetically engineered to express the MC4-R can be used for screening purposes. Preferably, host cells genetically
20 engineered to express a functional receptor that responds to activation by melanocortin peptides can be used as an endpoint in the assay; e.g., as measured by a chemical, physiological, biological, or phenotypic change, induction of a host cell gene or a reporter gene, change in cAMP levels,
25 adenylyl cyclase activity, host cell G protein activity, extracellular acidification rate, host cell kinase activity, proliferation, differentiation, etc.

In addition, cell-based assay systems can be used to screen for compounds that modulate the activity of mutant
30 MC4-R and thereby, modulate body weight. For example, compounds may be identified which increase the activity of mutant MC4-R thereby alleviating the symptoms of body weight disorders arising from mutant MC4-R. Cell lines, such as 293 cells, COS cells, CHO cells, fibroblasts and the like may be
35 genetically engineered to express mutant receptor. Alternatively, cells that endogenously express mutant MC4 receptor can be used to screen for compounds.

To be useful in screening assays, the host cells expressing functional MC4-R should give a significant response to MC4-R ligand, preferably greater than 5-fold induction over background. Host cells should preferably possess a number of characteristics, depending on the readout, to maximize the inductive response by melanocortin peptides, for example, for detecting a strong induction of a CRE reporter gene: (a) a low natural level of cAMP, (b) G proteins capable of interacting with the MC4-R, (c) a high level of adenylyl cyclase, (d) a high level of protein kinase A, (e) a low level of phosphodiesterases, and (f) a high level of cAMP response element binding protein would be advantageous. To increase response to melanocortin peptide, host cells could be engineered to express a greater amount of favorable factors or a lesser amount of unfavorable factors. In addition, alternative pathways for induction of the CRE reporter could be eliminated to reduce basal levels.

In utilizing such cell systems, the cells expressing the melanocortin receptor are exposed to a test compound or to vehicle controls (e.g., placebos). After exposure, the cells can be assayed to measure the expression and/or activity of components of the signal transduction pathway of the melanocortin receptor, or the activity of the signal transduction pathway itself can be assayed. For example, after exposure, cell lysates can be assayed for induction of cAMP. The ability of a test compound to increase levels of cAMP, above those levels seen with cells treated with a vehicle control, indicates that the test compound induces signal transduction mediated by the melanocortin receptor expressed by the host cell.

To determine intracellular cAMP concentrations, a scintillation proximity assay (SPA) may be utilized (SPA kit is provided by Amersham Life Sciences, Illinois). The assay utilizes ¹²⁵I label cAMP, an anti-cAMP antibody, and a scintillant-incorporated microsphere coated with a secondary antibody. When brought into close proximity to the microsphere through the labeled cAMP-antibody complex, ¹²⁵I

will excite the scintillant to emit light. Unlabeled cAMP extracted from cells competes with the ¹²⁵I-labeled cAMP for binding to the antibody and thereby diminishes scintillation. The assay may be performed in 96-well plates to enable high-throughput screening and 96 well-based scintillation counting instruments such as those manufactured by Wallac or Packard may be used for readout.

In screening for compounds that may act as antagonists of MC4-R, it is necessary to include ligands that activate the MC4-R, e.g., α -MSH, β -MSH or ACTH, to test for inhibition of signal transduction by the test compound as compared to vehicle controls.

In a specific embodiment of the invention, constructs containing the cAMP responsive element linked to any of a variety of different reporter genes may be introduced into cells expressing the melanocortin receptor. Such reporter genes may include but is not limited to chloramphenicol acetyltransferase (CAT), luciferase, GUS, growth hormone, or placental alkaline phosphatase (SEAP). Following exposure of the cells to the test compound, the level of reporter gene expression may be quantitated to determine the test compound's ability to regulate receptor activity. Alkaline phosphatase assays are particularly useful in the practice of the invention as the enzyme is secreted from the cell. Therefore, tissue culture supernatant may be assayed for secreted alkaline phosphatase. In addition, alkaline phosphatase activity may be measured by calorimetric, bioluminescent or chemiluminescent assays such as those described in Bronstein, I. et al. (1994, Biotechniques 17: 172-177). Such assays provide a simple, sensitive easily automatable detection system for pharmaceutical screening.

When it is desired to discriminate between the melanocortin receptors and to identify compounds that selectively agonize or antagonize the MC4-R, the assays described above should be conducted using a panel of host cells, each genetically engineered to express one of the melanocortin receptors (MC1-R through MC5-R). Expression of

the human melanocortin receptors is preferred for drug discovery purposes. To this end, host cells can be genetically engineered to express any of the amino acid sequences shown for melanocortin receptors 1 through 5 in

5 FIG. 1. The cloning and characterization of each receptor has been described: MC1-R and MC2-R (Mountjoy., 1992, Science 257: 1248-1251; Chhajlani & Wikberg, 1992 FEBS Lett. 309: 417-420); MC3-R (Roselli-Rehfuss et al., 1993, Proc. Natl. Acad. Sci., USA 90: 8856-8860; Gantz et al., 1993, J. Biol. Chem. 268: 8246-8250); MC4-R (Gantz et al., 1993, J. Biol. Chem. 268: 15174-15179; Mountjoy et al., 1994, Mol. Endo. 8: 1298-1308); and MC5-R (Chhajlani et al., 1993, Biochem. Biophys. Res. Commun. 195: 866-873; Gantz et al., 1994, Biochem. Biophys. Res. Commun. 200: 1214-1220), each of
10 which is incorporated by reference herein in its entirety. Thus, each of the foregoing sequences can be utilized to engineer a cell or cell line that expresses one of the melanocortin receptors for use in screening assays described herein. To identify compounds that specifically or
15 selectively regulate MC4-R activity, the activation, or inhibition of MC4-R activation is compared to the effect of the test compound on the other melanocortin receptors.

In a specific embodiment, MC1-R through MC5-R cDNAs are expressed in 293 cells under the transcriptional control of
25 the CMV promoter. Stable cell lines are established. Because transfected human MC2-R (ACTH-R) did not express very well in 293 cells, the human adrenocortical carcinoma cell line H295 (ATCC No. CRL-2128), which expresses endogenous ACTH-R, may be used in screening assays in addition to a stable cell line
30 that expresses transfected ACTH-R. In the first round of screening, the MC4-R expressing cell line is used to identify candidate compounds that activated the MC4-R. Once identified, those candidate compounds can be tested to determine whether they selectively activate the MC4-R. The
35 activation of the melanocortin receptors may be assayed using, for example, the SPA assay described above.

Alternatively, if the host cells express more than one melanocortin peptide receptor, the background signal produced by these receptors in response to melanocortin peptides must be "subtracted" from the signal (see Gantz et al., supra).

5 The background response produced by these non-MC4-R melanocortin receptors can be determined by a number of methods, including elimination of MC4-R activity by antisense, antibody or antagonist. In this regard, it should be noted that wild type CHO cells demonstrate a small

10 endogenous response to melanocortin peptides which must be subtracted from background. Alternatively, activity contributed from other melanocortin receptors could be eliminated by activating host cells with a MC4-R-specific ligand, or including specific inhibitors of the other

15 melanocortin receptors.

5.2.2. NON-CELL BASED ASSAYS

In addition to cell based assays, non-cell based assay systems may be used to identify compounds that interact with,

20 e.g., bind to MC4-R. Such compounds may act as antagonists or agonists of MC4-R activity and may be used in the treatment of body weight disorders.

Isolated membranes may be used to identify compounds that interact with MC4-R. For example, in a typical

25 experiment using isolated membranes, 293 cells may be genetically engineered to express the MC4-R. Membranes can be harvested by standard techniques and used in an in vitro binding assay. ¹²⁵I-labelled ligand (e.g., ¹²⁵I-labelled α -MSH, β -MSH, or ACTH) is bound to the membranes and assayed for

30 specific activity; specific binding is determined by comparison with binding assays performed in the presence of excess unlabelled ligand.

To identify MC4-R ligands, membranes are incubated with labelled ligand in the presence or absence of test compound.

35 Compounds that bind to the receptor and compete with labelled ligand for binding to the membranes reduced the signal compared to the vehicle control samples.

Alternatively, soluble MC4-R may be recombinantly expressed and utilized in non-cell based assays to identify compounds that bind to MC4-R. The recombinantly expressed MC4-R polypeptides or fusion proteins containing one or more of the ECDs of MC4-R prepared as described in Section 5.3.1, infra, can be used in the non-cell based screening assays. Alternatively, peptides corresponding to one or more of the CDs of MC4-R, or fusion proteins containing one or more of the CDs of MC4-R can be used in non-cell based assay systems to identify compounds that bind to the cytoplasmic portion of the MC4-R; such compounds may be useful to modulate the signal transduction pathway of the MC4-R. In non-cell based assays the recombinantly expressed MC4-R is attached to a solid substrate such as a test tube, microtitre well or a column, by means well known to those in the art (see Ausubel et al., supra). The test compounds are then assayed for their ability to bind to the MC4-R.

In one aspect of the invention the screens may be designed to identify compounds that antagonize the interaction between MC4-R and MC4-R ligands such as α -MSH, β -MSH and ACTH. In such screens, the MC4-R ligands are labelled and test compounds can be assayed for their ability to antagonize the binding of labelled ligand to MC4-R.

25 5.2.3. ASSAYS FOR COMPOUNDS OR COMPOSITIONS THAT MODULATE EXPRESSION OF THE MC4-R

In vitro cell based assays may be designed to screen for compounds that regulate MC4-R expression at either the transcriptional or translational level.

30 In one embodiment, DNA encoding a reporter molecule can be linked to a regulatory element of the MC4-r gene and used in appropriate intact cells, cell extracts or lysates to identify compounds that modulate MC4-r gene expression. Appropriate cells or cell extracts are prepared from any cell type that normally expresses the MC4-r gene, thereby ensuring
35 that the cell extracts contain the transcription factors required for in vitro or in vivo transcription. The screen

can be used to identify compounds that modulate the expression of the reporter construct. In such screens, the level of reporter gene expression is determined in the presence of the test compound and compared to the level of
5 expression in the absence of the test compound.

To identify compounds that regulate MC4-R translation, cells or in vitro cell lysates containing MC4-R transcripts may be tested for modulation of MC4-R mRNA translation. To assay for inhibitors of MC4-R translation, test compounds are
10 assayed for their ability to modulate the translation of MC4-R mRNA in in vitro translation extracts.

Compounds that decrease the level of MC4-R expression, either at the transcriptional or translational level, may be useful for treatment of body weight disorders such as
15 anorexia and cachexia. In contrast, those compounds that increase the expression of MC4-R may be useful for treatment of disorders such as obesity.

5.2.4. COMPOUNDS THAT CAN BE SCREENED IN ACCORDANCE WITH THE INVENTION

20 The assays described above can identify compounds which affect MC4-R activity. For example, compounds that affect MC4-R activity include but are not limited to compounds that bind to the MC4-R, inhibit binding of the natural ligand, and
25 either activate signal transduction (agonists) or block activation (antagonists), and compounds that bind to the natural ligand of the MC4-R and neutralize ligand activity. Compounds that affect MC4-r gene activity (by affecting MC4-r gene expression, including molecules, e.g., proteins or small
30 organic molecules, that affect transcription or interfere with splicing events so that expression of the full length or the truncated form of the MC4-R can be modulated) can also be identified on the screens of the invention. However, it should be noted that the assays described can also identify
35 compounds that modulate MC4-R signal transduction (e.g., compounds which affect downstream signalling events, such as inhibitors or enhancers of G protein activities which

participate in transducing the signal activated by ligand binding to the MC4-R). The identification and use of such compounds which affect signalling events downstream of MC4-R and thus modulate effects of MC4-R on the development of body weight disorders are within the scope of the invention. In some instances, G protein-coupled receptors response has been observed to subside, or become desensitized with prolonged exposure to ligand. In an embodiment of the invention assays may be utilized to identify compounds that block the desensitization of the MC4-receptor, such compounds may be used to sustain the activity of the MC4-receptor, such compounds may be used to sustain the activity of the MC4-R receptor. Such compounds can be used as part of a therapeutic method for the treatment of body weight disorders.

The compounds which may be screened in accordance with the invention include, but are not limited to peptides, antibodies and fragments thereof, and other organic compounds (e.g., peptidomimetics) that bind to the ECD of the MC4-R and either mimic the activity triggered by the natural ligand (i.e., agonists) or inhibit the activity triggered by the natural ligand (i.e., antagonists); as well as peptides, antibodies or fragments thereof, and other organic compounds that include the ECD of the MC4-R (or a portion thereof) and bind to and "neutralize" natural ligand.

Compounds may include, but are not limited to, peptides such as, for example, soluble peptides, including but not limited to members of random peptide libraries; (see, e.g., Lam, K.S. et al., 1991, Nature 354:82-84; Houghten, R. et al., 1991, Nature 354:84-86), and combinatorial chemistry-derived molecular library made of D- and/or L- configuration amino acids, phosphopeptides (including, but not limited to, members of random or partially degenerate, directed phosphopeptide libraries; see, e.g., Songyang, Z. et al., 1993, Cell 72:767-778), antibodies (including, but not limited to, polyclonal, monoclonal, humanized, anti-idiotypic, chimeric or single chain antibodies, and FAb,

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F(ab')₂ and FAb expression library fragments, and epitope-binding fragments thereof), and small organic or inorganic molecules.

Other compounds which can be screened in accordance with the invention include but are not limited to small organic molecules that are able to cross the blood-brain barrier, gain entry into an appropriate cell and affect the expression of the MC4-R gene or some other gene involved in the MC4-R signal transduction pathway (e.g., by interacting with the regulatory region or transcription factors involved in gene expression); or such compounds that affect the activity of the MC4-R or the activity of some other intracellular factor involved in the MC4-R signal transduction pathway, such as, for example, the MC4-R associated G protein.

Computer modelling and searching technologies permit identification of compounds, or the improvement of already identified compounds, that can modulate MC4-R expression or activity. Having identified such a compound or composition, the active sites or regions are identified. Such active sites might typically be ligand binding sites. The active site can be identified using methods known in the art including, for example, from the amino acid sequences of peptides, from the nucleotide sequences of nucleic acids, or from study of complexes of the relevant compound or composition with its natural ligand. In the latter case, chemical or X-ray crystallographic methods can be used to find the active site by finding where on the factor the complexed ligand is found.

Next, the three dimensional geometric structure of the active site is determined. This can be done by known methods, including X-ray crystallography, which can determine a complete molecular structure. On the other hand, solid or liquid phase NMR can be used to determine certain intramolecular distances. Any other experimental method of structure determination can be used to obtain partial or complete geometric structures. The geometric structures may be measured with a complexed ligand, natural or artificial,

which may increase the accuracy of the active site structure determined.

If an incomplete or insufficiently accurate structure is determined, the methods of computer based numerical modelling can be used to complete the structure or improve its accuracy. Any recognized modelling method may be used, including parameterized models specific to particular biopolymers such as proteins or nucleic acids, molecular dynamics models based on computing molecular motions, statistical mechanics models based on thermal ensembles, or combined models. For most types of models, standard molecular force fields, representing the forces between constituent atoms and groups, are necessary, and can be selected from force fields known in physical chemistry. The incomplete or less accurate experimental structures can serve as constraints on the complete and more accurate structures computed by these modeling methods.

Finally, having determined the structure of the active site, either experimentally, by modeling, or by a combination, candidate modulating compounds can be identified by searching databases containing compounds along with information on their molecular structure. Such a search seeks compounds having structures that match the determined active site structure and that interact with the groups defining the active site. Such a search can be manual, but is preferably computer assisted. These compounds found from this search are potential MC4-R modulating compounds.

Alternatively, these methods can be used to identify improved modulating compounds from an already known modulating compound or ligand. The composition of the known compound can be modified and the structural effects of modification can be determined using the experimental and computer modelling methods described above applied to the new composition. The altered structure is then compared to the active site structure of the compound to determine if an improved fit or interaction results. In this manner systematic variations in composition, such as by varying side

groups, can be quickly evaluated to obtain modified modulating compounds or ligands of improved specificity or activity.

Further experimental and computer modeling methods
5 useful to identify modulating compounds based upon identification of the active sites of MC4-R, and related transduction and transcription factors will be apparent to those of skill in the art.

Examples of molecular modelling systems are the CHARMM
10 and QUANTA programs (Polygen Corporation, Waltham, MA). CHARMM performs the energy minimization and molecular dynamics functions. QUANTA performs the construction, graphic modelling and analysis of molecular structure. QUANTA allows interactive construction, modification,
15 visualization, and analysis of the behavior of molecules with each other.

A number of articles review computer modelling of drugs interactive with specific proteins, such as Rotivinen, et al.) 1988, Acta Pharmaceutical Fennica 97:159-166); Ripka
20 (1988 New Scientist 54-57); McKinaly and Rossmann (1989, Annu. Rev. Pharmacol. Toxiciol. 29:111-122); Perry and Davies, OSAR: Quantitative Structure-Activity Relationships in Drug Design pp. 189-193 Alan R. Liss, Inc. 1989; Lewis and Dean (1989, Proc. R. Soc. Lond. 236:125-140 and 141-162);
25 and, with respect to a model receptor for nucleic acid components, Askew, et al. (1989, J. Am. Chem. Soc. 111:1082-1090). Other computer programs that screen and graphically depict chemicals are available from companies such as BioDesign, Inc. (Pasadena, CA.), Allelix, Inc. (Mississauga,
30 Ontario, Canada), and Hypercube, Inc. (Cambridge, Ontario). Although these are primarily designed for application to drugs specific to particular proteins, they can be adapted to design of drugs specific to regions of DNA or RNA, once that region is identified.

35 Although described above with reference to design and generation of compounds which could alter binding, one could also screen libraries of known compounds, including natural

products or synthetic chemicals, and biologically active materials, including proteins, for compounds which are inhibitors or activators.

Compounds identified via assays such as those described herein may be useful, for example, in elaborating the biological function of the MC4-R gene product, and for ameliorating body weight disorders. Assays for testing the efficacy of compounds identified in the cellular screen can be tested in animal model systems for body weight disorders. Such animal models may be used as test substrates for the identification of drugs, pharmaceuticals, therapies and interventions which may be effective in treating such disorders. For example, animal models may be exposed to a compound, suspected of exhibiting an ability to ameliorate body weight disorder symptoms, at a sufficient concentration and for a time sufficient to elicit such an amelioration of body weight disorder symptoms in the exposed animals. The response of the animals to the exposure may be monitored by assessing the reversal of disorders associated with body weight disorders such as obesity. With regard to intervention, any treatments which reverse any aspect of body weight disorder-like symptoms should be considered as candidates for human body weight disorder therapeutic intervention. Dosages of test agents may be determined by deriving dose-response curves, as discussed in Section 5.5, below.

To this end, transgenic animals that express the human MC4-r gene products can be used. Animals of any species, including, but not limited to, mice, rats, rabbits, guinea pigs, pigs, micro-pigs, goats, and non-human primates, e.g., baboons, monkeys, and chimpanzees may be used to generate MC4-R transgenic animals.

Any technique known in the art may be used to introduce the human MC4-r transgene into animals to produce the founder lines of transgenic animals. Such techniques include, but are not limited to pronuclear microinjection (Hoppe, P.C. and Wagner, 1989, U.S. Pat. No. 4,873,191); retrovirus mediated

gene transfer into germ lines (Van der Putten et al., 1985, Proc. Natl. Acad. Sci., USA 82:6148-6152); gene targeting in embryonic stem cells (Thompson et al., 1989, Cell 56:313-321); electroporation of embryos (Lo, 1983, Mol Cell. Biol. 3:1803-1814); and sperm-mediated gene transfer (Lavitrano et al., 1989, Cell 57:717-723); etc. For a review of such techniques, see Gordon, 1989, Transgenic Animals, Intl. Rev. Cytol. 115:171-229, which is incorporated by reference herein in its entirety.

10 The present invention provides for transgenic animals that carry the MC4-r transgene in all their cells, as well as animals which carry the transgene in some, but not all their cells, i.e., mosaic animals. The transgene may be integrated as a single transgene or in concatamers, e.g., head-to-head
15 tandems or head-to-tail tandems. The transgene may also be selectively introduced into and activated in a particular cell type by following, for example, the teaching of Lasko et al. (Lasko, M. et al., 1992, Proc. Natl. Acad. Sci. USA 89: 6232-6236). The regulatory sequences required for such a
20 cell-type specific activation will depend upon the particular cell type of interest, and will be apparent to those of skill in the art. When it is desired that the MC4-r transgene be integrated into the chromosomal site of the endogenous MC4-r gene, gene targeting is preferred. Briefly, when such a
25 technique is to be utilized, vectors containing nucleotide sequences homologous to the endogenous MC4-r gene and/or sequences flanking the gene are designed for the purpose of integrating, via homologous recombination with chromosomal sequences, into and disrupting the function of the endogenous
30 MC4-r gene. The transgene may also be selectively expressed in a particular cell type with concomitant inactivation of the endogenous MC4-r gene in only that cell type, by following, for example, the teaching of Gu et al. (Gu, et al., 1994, Science 265: 103-106). The regulatory sequences
35 required for such a cell-type specific recombination will depend upon the particular cell type of interest, and will be apparent to those of skill in the art.

Once founder animals have been generated, standard techniques such as Southern blot analysis or PCR techniques are used to analyze animal tissues to determine whether integration of the transgene has taken place. The level of mRNA expression of the transgene in the tissues of the founder animals may also be assessed using techniques which include but are not limited to Northern blot analysis of tissue samples obtained from the animal, in situ hybridization analysis, and RT-PCR. Samples of MC4-R gene-expressing tissue, may also be evaluated immunocytochemically using antibodies specific for the MC4-R transgene product.

5.3. MC4-R PROTEINS, POLYPEPTIDES, AND ANTIBODIES

MC4-R protein, polypeptides and peptide fragments, mutated, truncated or deleted forms of the MC4-R and/or MC4-R fusion proteins can be prepared for a variety of uses, including but not limited to the generation of antibodies, as reagents in diagnostic assays, the identification of other cellular gene products involved in the regulation of body weight, as reagents in assays for screening for compounds that can be used in the treatment of body weight disorders, and as pharmaceutical reagents useful in the treatment of body weight disorders related to the MC4-R.

25 5.3.1. PRODUCTION OF MC4-R POLYPEPTIDES

The deduced amino acid sequences of the melanocortin receptors, including MC4-R, are shown in FIG. 1, where predicted transmembrane domains are denoted by overbars and Roman numerals, and the four extracellular domains (ECD1, ECD2, ECD3, and ECD4) and the four cytoplasmic domains (CD1, CD2, CD3 and CD4) are indicated. The serpentine structure of the melanocortin receptors predicts that the hydrophilic domains located between the TM domains are arranged alternately outside and within the cell to form the ECD (amino acid residues 1-74, 137-155, 219-231 and 305-316 in FIG. 1) and the CD (amino acid residues 102-112, 178-197, 251-280 and 339-end in FIG. 1) of the receptor. Peptides

corresponding to one or more domains of the MC4-R (e.g., ECDs, TMs or CDs), truncated or deleted MC4-R (e.g., MC4-R in which one or more of the ECDs, TMs and/or CDs is deleted) as well as fusion proteins in which the full length MC4-R, an MC4-R peptide or truncated MC4-R is fused to an unrelated protein are also within the scope of the invention. Such soluble peptides, proteins, fusion proteins, or antibodies (including anti-idiotypic antibodies) that bind to and "neutralize" circulating natural ligand for the MC4-R, can be used as described in Section 5,5, infra, to effectuate weight gain. To this end, peptides corresponding to individual ECDs of MC4-R, soluble deletion mutants of MC4-R (e.g., Δ TM mutants), or the entire MC4-R ECD (engineered by linking the four ECDs together as described below) can be fused to another polypeptide (e.g., an IgFc polypeptide). Fusion of the MC4-R or the MC4-R ECD to an IgFc polypeptide should not only increase the stability of the preparation, but will increase the half-life and activity of the MC4-R-Ig fusion protein in vivo. The Fc region of the Ig portion of the fusion protein may be further modified to reduce immunoglobulin effector function.

Such peptides, polypeptides, and fusion proteins can be prepared by recombinant DNA techniques. For example, nucleotide sequences encoding one or more of the four domains of the ECD of the serpentine MC4-R can be synthesized or cloned and ligated together to encode a soluble ECD of the MC4-R. The DNA sequence encoding one or more of the four ECDs (ECD1-4 in FIG. 1) can be ligated together directly or via a linker oligonucleotide that encodes a peptide spacer. Such linkers may encode flexible, glycine-rich amino acid sequences thereby allowing the domains that are strung together to assume a conformation that can bind MC4-R ligands. Alternatively, nucleotide sequences encoding individual domains within the ECD can be used to express MC4-R peptides. In addition, mutant MC4-R proteins such as those shown in FIGS. 11-13 can be expressed by recombinant DNA techniques.

A variety of host-expression vector systems may be utilized to express nucleotide sequences encoding the appropriate regions of the MC4-R to produce such polypeptides. Where the resulting peptide or polypeptide is a soluble derivative (e.g., peptides corresponding to the ECDs; truncated or deleted in which the TMs and/or CDs are deleted) the peptide or polypeptide can be recovered from the culture media. Where the polypeptide or protein is not secreted, the MC4-R product can be recovered from the host cell itself.

The host-expression vector systems also encompass engineered host cells that express the MC4-R or functional equivalents in situ, i.e., anchored in the cell membrane. Purification or enrichment of the MC4-R from such expression systems can be accomplished using appropriate detergents and lipid micelles and methods well known to those skilled in the art. However, such engineered host cells themselves may be used in situations where it is important not only to retain the structural and functional characteristics of the MC4-R, but to assess biological activity, e.g., in drug screening assays.

Alternatively, host-expression vector systems may be used to engineer host cells that express mutant MC4-R protein (see, for example FIG. 11-13). Such host cells may be used to assess biological activity, e.g., in drug screening assays.

The host-expression vector systems that may be used for purposes of the invention include but are not limited to microorganisms such as bacteria (e.g., E. coli, B. subtilis) transformed with recombinant bacteriophage DNA, plasmid DNA or cosmid DNA expression vectors containing MC4-R nucleotide sequences; yeast (e.g., Saccharomyces, Pichia) transformed with recombinant yeast expression vectors containing the MC4-R nucleotide sequences; insect cell systems infected with recombinant virus expression vectors (e.g., baculovirus) containing the MC4-R sequences; plant cell systems infected with recombinant virus expression vectors (e.g., cauliflower

mosaic virus, CaMV; tobacco mosaic virus, TMV) or transformed with recombinant plasmid expression vectors (e.g., Ti plasmid) containing MC4-R nucleotide sequences; or mammalian cell systems (e.g., COS, CHO, BHK, 293, 3T3) harboring recombinant expression constructs containing promoters derived from the genome of mammalian cells (e.g., metallothionein promoter) or from mammalian viruses (e.g., the adenovirus late promoter; the vaccinia virus 7.5K promoter).

10 In bacterial systems, a number of expression vectors may be advantageously selected depending upon the use intended for the MC4-R gene product being expressed. For example, when a large quantity of such a protein is to be produced, for the generation of pharmaceutical compositions of MC4-R
15 protein or for raising antibodies to the MC4-R protein, for example, vectors which direct the expression of high levels of fusion protein products that are readily purified may be desirable. Such vectors include, but are not limited, to the E. coli expression vector pUR278 (Ruther et al., 1983, EMBO
20 J. 2:1791), in which the MC4-R coding sequence may be ligated individually into the vector in frame with the lacZ coding region so that a fusion protein is produced; pIN vectors (Inouye & Inouye, 1985, Nucleic Acids Res. 13:3101-3109; Van Heeke & Schuster, 1989, J. Biol. Chem. 264:5503-5509); and
25 the like. pGEX vectors may also be used to express foreign polypeptides as fusion proteins with glutathione S-transferase (GST). In general, such fusion proteins are soluble and can easily be purified from lysed cells by adsorption to glutathione-agarose beads followed by elution
30 in the presence of free glutathione. The PGEX vectors are designed to include thrombin or factor Xa protease cleavage sites so that the cloned target gene product can be released from the GST moiety.

Alternatively, any fusion protein may be readily
35 purified by utilizing an antibody specific for the fusion protein being expressed. For example, a system described by Janknecht et al. allows for the ready purification of non-

denatured fusion proteins expressed in human cell lines (Janknecht, et al., 1991, Proc. Natl. Acad. Sci. USA 88: 8972-8976). In this system, the gene of interest is subcloned into a vaccinia recombination plasmid such that the gene's open reading frame is translationally fused to an amino-terminal tag consisting of six histidine residues. Extracts from cells infected with recombinant vaccinia virus are loaded onto Ni^{2+} nitriloacetic acid-agarose columns and histidine-tagged proteins are selectively eluted with imidazole-containing buffers.

In an insect system, Autographa californica nuclear polyhedrosis virus (AcNPV) is used as a vector to express foreign genes. The virus grows in Spodoptera frugiperda cells. The MC4-R coding sequence may be cloned individually into non-essential regions (for example the polyhedrin gene) of the virus and placed under control of an AcNPV promoter (for example the polyhedrin promoter). Successful insertion of MC4-R gene coding sequence will result in inactivation of the polyhedrin gene and production of non-occluded recombinant virus (i.e., virus lacking the proteinaceous coat coded for by the polyhedrin gene). The recombinant viruses are then used to infect cells in which the inserted gene is expressed. (E.g., see Smith et al., 1983, J. Virol. 46: 584; Smith, U.S. Patent No. 4,215,051).

In mammalian host cells, a number of viral-based expression systems may be utilized. In cases where an adenovirus is used as an expression vector, the MC4-R nucleotide sequence of interest may be ligated to an adenovirus transcription/translation control complex, e.g., the late promoter and tripartite leader sequence. This chimeric gene may then be inserted in the adenovirus genome by in vitro or in vivo recombination. Insertion in a non-essential region of the viral genome (e.g., region E1 or E3) will result in a recombinant virus that is viable and capable of expressing the MC4-R gene product in infected hosts.

(E.g., See Logan & Shenk, 1984, Proc. Natl. Acad. Sci. USA 81:3655-3659). Specific initiation signals may also be

required for efficient translation of inserted MC4-R nucleotide sequences. These signals include the ATG initiation codon and adjacent sequences. In cases where an entire MC4-R gene or cDNA, including its own initiation codon and adjacent sequences, is inserted into the appropriate expression vector, no additional translational control signals may be needed. However, in cases where only a portion of the MC4-R coding sequence is inserted, exogenous translational control signals, including, perhaps, the ATG initiation codon, must be provided. Furthermore, the initiation codon must be in frame with the reading frame of the desired coding sequence to ensure translation of the entire insert. These exogenous translational control signals and initiation codons can be of a variety of origins, both natural and synthetic. The efficiency of expression may be enhanced by the inclusion of appropriate transcription enhancer elements, transcription terminators, etc. (See Bittner et al., 1987, Methods in Enzymol. 153:516-544).

In addition, a host cell strain may be chosen which modulates the expression of the inserted sequences, or modifies and processes the gene product in the specific fashion desired. Such modifications (e.g., glycosylation) and processing (e.g., cleavage) of protein products may be important for the function of the protein. Different host cells have characteristic and specific mechanisms for the post-translational processing and modification of proteins and gene products. Appropriate cell lines or host systems can be chosen to ensure the correct modification and processing of the foreign protein expressed. Accordingly, eukaryotic host cells which possess the cellular machinery for proper processing of the primary transcript, glycosylation, and phosphorylation of the gene product may be used. Such mammalian host cells include, but are not limited to, CHO, VERO, BHK, HeLa, COS, MDCK, 293, 3T3 and WI38 cell lines.

For long-term, high-yield production of recombinant proteins, stable expression is preferred. For example, cell

lines which stably express the MC4-R sequences described above may be engineered. Rather than using expression vectors which contain viral origins of replication, host cells can be transformed with DNA controlled by appropriate
 5 expression control elements (e.g., promoter, enhancer sequences, transcription terminators, polyadenylation sites, etc.), and a selectable marker. Following the introduction of the foreign DNA, engineered cells may be allowed to grow for 1-2 days in an enriched media, and then are switched to a
 10 selective media. The selectable marker in the recombinant plasmid confers resistance to the selection and allows cells to stably integrate the plasmid into their chromosomes and grow to form foci which in turn can be cloned and expanded into cell lines. This method may advantageously be used to
 15 engineer cell lines which express the MC4-R gene product. Such engineered cell lines may be particularly useful in screening and evaluation of compounds that affect the endogenous activity of the MC4-R gene product.

A number of selection systems may be used, including but
 20 not limited to the herpes simplex virus thymidine kinase (Wigler, et al., 1977, Cell 11:223), hypoxanthine-guanine phosphoribosyltransferase (Szybalska & Szybalski, 1962, Proc. Natl. Acad. Sci. USA 48:2026), and adenine
 phosphoribosyltransferase (Lowy, et al., 1980, Cell 22:817)
 25 genes can be employed in tk⁻, hgp^rt⁻ or ap^rt⁻ cells, respectively. Also, antimetabolite resistance can be used as the basis of selection for the following genes: dhfr, which confers resistance to methotrexate (Wigler, et al., 1980, Natl. Acad. Sci. USA 77:3567; O'Hare, et al., 1981, Proc.
 30 Natl. Acad. Sci. USA 78:1527); gpt, which confers resistance to mycophenolic acid (Mulligan & Berg, 1981, Proc. Natl. Acad. Sci. USA 78:2072); neo, which confers resistance to the aminoglycoside G-418 (Colberre-Garapin, et al., 1981, J. Mol. Biol. 150:1); and hyg^r, which confers resistance to
 35 hygromycin (Santerre, et al., 1984, Gene 30:147).

5.3.2. ANTIBODIES TO MC4-R POLYPEPTIDES

Antibodies that specifically recognize one or more epitopes of MC4-R, or epitopes of conserved variants of MC4-R, or peptide fragments of the MC4-R are also encompassed by the invention. Further, antibodies that specifically
5 recognize mutant forms of MC4-R, such as those encoded by the DNA sequences shown in Figures 11-13, are encompassed by the invention. Such antibodies include but are not limited to polyclonal antibodies, monoclonal antibodies (mAbs), humanized or chimeric antibodies, single chain antibodies,
10 Fab fragments, F(ab')₂ fragments, fragments produced by a Fab expression library, anti-idiotypic (anti-Id) antibodies, and epitope-binding fragments of any of the above.

The antibodies of the invention may be used, for example, in the detection of the MC4-R in a biological sample
15 and may, therefore, be utilized as part of a diagnostic or prognostic technique whereby patients may be tested for abnormal amounts of MC4-R. Antibodies that specifically recognize mutant forms of MC4-R, such as those described below, in Section 8, may be particularly useful as part of a
20 diagnostic or prognostic technique. Such antibodies may also be utilized in conjunction with, for example, compound screening schemes, as described, above, for the evaluation of the effect of test compounds on expression and/or activity of the MC4-R gene product. Additionally, such antibodies can be
25 used in conjunction with the gene therapy techniques described, below, e.g., to evaluate the normal and/or engineered MC4-R-expressing cells prior to their introduction into the patient. Such antibodies may additionally be used as a method for the inhibition of abnormal MC4-R activity.
30 Thus, such antibodies may, therefore, be utilized as part of weight disorder treatment methods.

For the production of antibodies, various host animals may be immunized by injection with the MC4-R, an MC4-R peptide (e.g., one corresponding to a functional domain of
35 the receptor, such as ECD, TM or CD), truncated MC4-R polypeptides (MC4-R in which one or more domains, e.g., the TM or CD, has been deleted), functional equivalents of the

MC4-R or mutants of the MC4-R. Such host animals may include but are not limited to rabbits, mice, hamsters and rats, to name but a few. Various adjuvants may be used to increase the immunological response, depending on the host species, including but not limited to Freund's (complete and incomplete), mineral gels such as aluminum hydroxide, surface active substances such as lysolecithin, pluronic polyols, polyanions, peptides, oil emulsions, keyhole limpet hemocyanin, dinitrophenol, and potentially useful human adjuvants such as BCG (bacille Calmette-Guerin) and Corynebacterium parvum. Polyclonal antibodies are heterogeneous populations of antibody molecules derived from the sera of the immunized animals.

Monoclonal antibodies, which are homogeneous populations of antibodies to a particular antigen, may be obtained by any technique which provides for the production of antibody molecules by continuous cell lines in culture. These include, but are not limited to, the hybridoma technique of Kohler and Milstein, (1975, Nature 256:495-497; and U.S. Patent No. 4,376,110), the human B-cell hybridoma technique (Kosbor et al., 1983, Immunology Today 4:72; Cole et al., 1983, Proc. Natl. Acad. Sci. USA 80:2026-2030), and the EBV-hybridoma technique (Cole et al., 1985, Monoclonal Antibodies And Cancer Therapy, Alan R. Liss, Inc., pp. 77-96). Such antibodies may be of any immunoglobulin class including IgG, IgM, IgE, IgA, IgD and any subclass thereof. The hybridoma producing the mAb of this invention may be cultivated in vitro or in vivo. Production of high titers of mAbs in vivo makes this the presently preferred method of production.

In addition, techniques developed for the production of "chimeric antibodies" (Morrison et al., 1984, Proc. Natl. Acad. Sci., 81:6851-6855; Neuberger et al., 1984, Nature, 312:604-608; Takeda et al., 1985, Nature, 314:452-454) by splicing the genes from a mouse antibody molecule of appropriate antigen specificity together with genes from a human antibody molecule of appropriate biological activity can be used. A chimeric antibody is a molecule in which

different portions are derived from different animal species, such as those having a variable region derived from a murine mAb and a human immunoglobulin constant region.

Alternatively, techniques described for the production of single chain antibodies (U.S. Patent 4,946,778; Bird, 1988, Science 242:423-426; Huston et al., 1988, Proc. Natl. Acad. Sci. USA 85:5879-5883; and Ward et al., 1989, Nature 334:544-546) can be adapted to produce single chain antibodies against MC4-R gene products. Single chain antibodies are formed by linking the heavy and light chain fragments of the Fv region via an amino acid bridge, resulting in a single chain polypeptide.

Antibody fragments which recognize specific epitopes may be generated by known techniques. For example, such fragments include but are not limited to: the F(ab')₂ fragments which can be produced by pepsin digestion of the antibody molecule and the Fab fragments which can be generated by reducing the disulfide bridges of the F(ab')₂ fragments. Alternatively, Fab expression libraries may be constructed (Huse et al., 1989, Science, 246:1275-1281) to allow rapid and easy identification of monoclonal Fab fragments with the desired specificity.

Antibodies to the MC4-R can, in turn, be utilized to generate anti-idiotypic antibodies that "mimic" the MC4-R, using techniques well known to those skilled in the art. (See, e.g., Greenspan & Bona, 1993, FASEB J 7(5):437-444; and Nissinoff, 1991, J. Immunol. 147(8):2429-2438). For example antibodies which bind to the MC4-R ECD and competitively inhibit the binding of melanocortins to the MC4-R can be used to generate anti-idiotypes that "mimic" the ECD and, therefore, bind and neutralize melanocortins. Such neutralizing anti-idiotypes or Fab fragments of such anti-idiotypes can be used in therapeutic regimens to neutralize the native ligand and promote weight gain.

Alternatively, antibodies to MC4-R that can act as agonists of MC4-R activity can be generated. Such antibodies will bind to the MC4-R and activate the signal transducing

activity of the receptor. Such antibodies would be particularly useful for treating weight disorders such as obesity. In addition, antibodies that act as antagonist of MC4-R activity, i.e. inhibit the activation of MC4-R receptor may be used to treat weight disorders such as anorexia or cachexia.

5.4. GENE THERAPY APPROACHES TO CONTROLLING MC4-R ACTIVITY AND REGULATING BODY WEIGHT

10 The expression of MC4-R can be controlled in vivo (e.g. at the transcriptional or translational level) using gene therapy approaches to regulate MC4-R activity and treat body weight disorders. Certain approaches are described below.

15 5.4.1. GENE REPLACEMENT THERAPY

With respect to an increase in the level of normal MC4-R gene expression and/or MC4-R gene product activity, MC4-R nucleic acid sequences can be utilized for the treatment of body weight disorders, including obesity. Where the cause of obesity is a defective MC4-R gene, treatment can be administered, for example, in the form of gene replacement therapy. Specifically, one or more copies of a normal MC4-R gene or a portion of the MC4-R gene that directs the production of an MC4-R gene product exhibiting normal function, may be inserted into the appropriate cells within a patient or animal subject, using vectors which include, but are not limited to adenovirus, adeno-associated virus, retrovirus and herpes virus vectors, in addition to other particles that introduce DNA into cells, such as liposomes.

30 Because the MC4-R gene is expressed in the brain, including the cortex, thalamus, brain stem and spinal cord and hypothalamus, such gene replacement therapy techniques should be capable of delivering MC4-R gene sequences to these cell types within patients. Thus, the techniques for delivery of the MC4-R gene sequences should be designed to readily cross the blood-brain barrier, which are well known to those of skill in the art (see, e.g., PCT application,

publication No. WO89/10134, which is incorporated herein by reference in its entirety), or, alternatively, should involve direct administration of such MC4-R gene sequences to the site of the cells in which the MC4-R gene sequences are to be
5 expressed.

Alternatively, targeted homologous recombination can be utilized to correct the defective endogenous MC4-R gene in the appropriate tissue; e.g., brain tissue. In animals, targeted homologous recombination can be used to correct the
10 defect in ES cells in order to generate offspring with a corrected trait.

Additional methods which may be utilized to increase the overall level of MC4-R gene expression and/or MC4-R activity include the introduction of appropriate MC4-R-expressing
15 cells, preferably autologous cells, into a patient at positions and in numbers which are sufficient to ameliorate the symptoms of body weight disorders, including obesity. Such cells may be either recombinant or non-recombinant. Among the cells which can be administered to increase the
20 overall level of MC4-R gene expression in a patient are normal cells, or hypothalamus cells which express the MC4-R gene. The cells can be administered at the anatomical site in the brain, or as part of a tissue graft located at a different site in the body. Such cell-based gene therapy
25 techniques are well known to those skilled in the art, see, e.g., Anderson, et al., U.S. Patent No. 5,399,349; Mulligan & Wilson, U.S. Patent No. 5,460,959.

Finally, compounds, identified in the assays described above, that stimulate or enhance the signal transduced by
30 activated MC4-R, e.g., by activating downstream signalling proteins in the MC4-R cascade and thereby by-passing the defective MC4-R, can be used to achieve weight loss. The formulation and mode of administration will depend upon the physico-chemical properties of the compound. The
35 administration should include known techniques that allow for a crossing of the blood-brain barrier.

5.4.2. INHIBITION OF MC4-R EXPRESSION

In an alternate embodiment, weight gain therapy can be designed to reduce the level of endogenous MC4-R gene expression, e.g., using antisense or ribozyme approaches to inhibit or prevent translation of MC4-R mRNA transcripts; triple helix approaches to inhibit transcription of the MC4-R gene; or targeted homologous recombination to inactivate or "knock out" the MC4-R gene or its endogenous promoter. Such gene therapy may be utilized for treatment of body weight disorders such as cachexia and anorexia where the inhibition of MC4-R expression is designed to increase body weight. Because the MC4-R gene is expressed in the brain, delivery techniques should be preferably designed to cross the blood-brain barrier (see PCT WO89/10134, which is incorporated by reference herein in its entirety). Alternatively, the antisense, ribozyme or DNA constructs described herein could be administered directly to the site containing the target cells.

Antisense approaches involve the design of oligonucleotides (either DNA or RNA) that are complementary to mRNA. The antisense oligonucleotides will bind to the complementary mRNA transcripts and prevent translation. Absolute complementarity, although preferred, is not required. A sequence "complementary" to a portion of an RNA, as referred to herein, means a sequence having sufficient complementarity to be able to hybridize with the RNA, forming a stable duplex; in the case of double-stranded antisense nucleic acids, a single strand of the duplex DNA may thus be tested, or triplex formation may be assayed. The ability to hybridize will depend on both the degree of complementarity and the length of the antisense nucleic acid. Generally, the longer the hybridizing nucleic acid, the more base mismatches with an RNA it may contain and still form a stable duplex (or triplex, as the case may be). One skilled in the art can ascertain a tolerable degree of mismatch by use of standard procedures to determine the melting point of the hybridized complex.

While antisense nucleotides complementary to the coding region sequence could be used, those complementary to the transcribed untranslated region are most preferred. Oligonucleotides that are complementary to the 5' end of the message, e.g., the 5' untranslated sequence up to and including the AUG initiation codon, should work most efficiently at inhibiting translation (see FIG. 5). However, sequences complementary to the 3' untranslated sequences of mRNAs have recently shown to be effective at inhibiting translation of mRNAs as well. See generally, Wagner, R., 1994, Nature 372:333-335. Thus, oligonucleotides complementary to either the 5'- or 3'- non-translated, non-coding regions of MC4-R could be used in an antisense approach to inhibit translation of endogenous mRNA.

Oligonucleotides complementary to the 5' untranslated region of the mRNA should include the complement of the AUG start codon. Antisense oligonucleotides complementary to mRNA coding regions are less efficient inhibitors of translation but could be used in accordance with the invention. Whether designed to hybridize to the 5'-, 3'- or coding region of MC4-R mRNA, antisense nucleic acids should be at least six nucleotides in length, and are preferably oligonucleotides ranging from 6 to about 50 nucleotides in length. In specific aspects the oligonucleotide is at least 10 nucleotides, at least 17 nucleotides, at least 25 nucleotides or at least 50 nucleotides.

Regardless of the choice of target sequence, it is preferred that *in vitro* studies are first performed to quantitate the ability of the antisense oligonucleotide to inhibit gene expression. It is preferred that these studies utilize controls that distinguish between antisense gene inhibition and nonspecific biological effects of oligonucleotides. It is also preferred that these studies compare levels of the target RNA or protein with that of an internal control RNA or protein. Additionally, it is envisioned that results obtained using the antisense oligonucleotide are compared with those obtained using a

control oligonucleotide. It is preferred that the control oligonucleotide is of approximately the same length as the test oligonucleotide and that the nucleotide sequence of the oligonucleotide differs from the antisense sequence no more
 5 than is necessary to prevent specific hybridization to the target sequence.

The oligonucleotides can be DNA or RNA or chimeric mixtures or derivatives or modified versions thereof, single-stranded or double-stranded. The oligonucleotide can be
 10 modified at the base moiety, sugar moiety, or phosphate backbone, for example, to improve stability of the molecule, hybridization, etc. The oligonucleotide may include other appended groups such as peptides (e.g., for targeting host cell receptors in vivo), or agents facilitating transport
 15 across the cell membrane (see, e.g., Letsinger et al., 1989, Proc. Natl. Acad. Sci. U.S.A. 86:6553-6556; Lemaitre et al., 1987, Proc. Natl. Acad. Sci. 84:648-652; PCT Publication No. WO88/09810, published December 15, 1988) or the blood-brain barrier (see, e.g., PCT Publication No. WO89/10134, published
 20 April 25, 1988), hybridization-triggered cleavage agents. (See, e.g., Krol et al., 1988, BioTechniques 6:958-976) or intercalating agents. (See, e.g., Zon, 1988, Pharm. Res. 5:539-549). To this end, the oligonucleotide may be conjugated to another molecule, e.g., a peptide,
 25 hybridization triggered cross-linking agent, transport agent, hybridization-triggered cleavage agent, etc.

The antisense oligonucleotide may comprise at least one modified base moiety which is selected from the group including but not limited to 5-fluorouracil, 5-bromouracil,
 30 5-chlorouracil, 5-iodouracil, hypoxanthine, xantine, 4-acetylcytosine, 5-(carboxyhydroxymethyl) uracil, 5-carboxymethylaminomethyl-2-thiouridine, 5-carboxymethylaminomethyluracil, dihydrouracil, beta-D-galactosylqueosine, inosine, N6-isopentenyladenine,
 35 1-methylguanine, 1-methylinosine, 2,2-dimethylguanine, 2-methyladenine, 2-methylguanine, 3-methylcytosine, 5-methylcytosine, N6-adenine, 7-methylguanine,

5-methylaminomethyluracil, 5-methoxyaminomethyl-2-thiouracil, beta-D-mannosylqueosine, 5'-methoxycarboxymethyluracil, 5-methoxyuracil, 2-methylthio-N6-isopentenyladenine, uracil-5-oxyacetic acid (v), wybutoxosine, pseudouracil, 5 queosine, 2-thiocytosine, 5-methyl-2-thiouracil, 2-thiouracil, 4-thiouracil, 5-methyluracil, uracil-5-oxyacetic acid methylester, uracil-5-oxyacetic acid (v), 5-methyl-2-thiouracil, 3-(3-amino-3-N-2-carboxypropyl) uracil, (acp3)w, and 2,6-diaminopurine.

10 The antisense oligonucleotide may also comprise at least one modified sugar moiety selected from the group including but not limited to arabinose, 2-fluoroarabinose, xylulose, and hexose.

In yet another embodiment, the antisense oligonucleotide 15 comprises at least one modified phosphate backbone selected from the group consisting of a phosphorothioate, a phosphorodithioate, a phosphoramidothioate, a phosphoramidate, a phosphordiamidate, a methylphosphonate, an alkyl phosphotriester, and a formacetal or analog thereof.

20 In yet another embodiment, the antisense oligonucleotide is an α -anomeric oligonucleotide. An α -anomeric oligonucleotide forms specific double-stranded hybrids with complementary RNA in which, contrary to the usual β -units, the strands run parallel to each other (Gautier et al., 1987, 25 Nucl. Acids Res. 15:6625-6641). The oligonucleotide is a 2'-O-methylribonucleotide (Inoue et al., 1987, Nucl. Acids Res. 15:6131-6148), or a chimeric RNA-DNA analogue (Inoue et al., 1987, FEBS Lett. 215:327-330).

Oligonucleotides of the invention may be synthesized by 30 standard methods known in the art, e.g. by use of an automated DNA synthesizer (such as are commercially available from Biosearch, Applied Biosystems, etc.). As examples, phosphorothioate oligonucleotides may be synthesized by the method of Stein et al. (1988, Nucl. Acids Res. 16:3209), 35 methylphosphonate oligonucleotides can be prepared by use of controlled pore glass polymer supports (Sarin et al., 1988, Proc. Natl. Acad. Sci. U.S.A. 85:7448-7451), etc.

The antisense molecules should be delivered to cells which express the MC4-R in vivo, e.g., neural tissue. A number of methods have been developed for delivering antisense DNA or RNA to cells; e.g., antisense molecules can be injected directly into the tissue site, or modified antisense molecules, designed to target the desired cells (e.g., antisense linked to peptides or antibodies that specifically bind receptors or antigens expressed on the target cell surface) can be administered systemically.

However, it is often difficult to achieve intracellular concentrations of the antisense sufficient to suppress translation of endogenous mRNAs. Therefore a preferred approach utilizes a recombinant DNA construct in which the antisense oligonucleotide is placed under the control of a strong pol III or pol II promoter. The use of such a construct to transfect target cells in the patient will result in the transcription of sufficient amounts of single stranded RNAs that will form complementary base pairs with the endogenous MC4-R transcripts and thereby prevent translation of the MC4-R mRNA. For example, a vector can be introduced in vivo such that it is taken up by a cell and directs the transcription of an antisense RNA. Such a vector can remain episomal or become chromosomally integrated, as long as it can be transcribed to produce the desired antisense RNA. Such vectors can be constructed by recombinant DNA technology methods standard in the art. Vectors can be plasmid, viral, or others known in the art, used for replication and expression in mammalian cells. Expression of the sequence encoding the antisense RNA can be by any promoter known in the art to act in mammalian, preferably human cells. Such promoters can be inducible or constitutive. Such promoters include but are not limited to: the SV40 early promoter region (Bernoist and Chambon, 1981, Nature 290:304-310), the promoter contained in the 3' long terminal repeat of Rous sarcoma virus (Yamamoto et al., 1980, Cell 22:787-797), the herpes thymidine kinase promoter (Wagner et al., 1981, Proc. Natl. Acad. Sci. U.S.A. 78:1441-

1445), the regulatory sequences of the metallothionein gene (Brinster et al., 1982, Nature 296:39-42), etc. Any type of plasmid, cosmid, YAC or viral vector can be used to prepare the recombinant DNA construct which can be introduced
5 directly into the tissue site; e.g., the choroid plexus or hypothalamus. Alternatively, viral vectors can be used which selectively infect the desired tissue; (e.g., for brain, herpesvirus vectors may be used), in which case administration may be accomplished by another route (e.g.,
10 systemically).

Ribozyme molecules designed to catalytically cleave MC4-R mRNA transcripts can also be used to prevent translation of MC4-R mRNA and expression of MC4-R. (See, e.g., PCT International Publication WO90/11364, published October 4,
15 1990; Sarver et al., 1990, Science 247:1222-1225). While ribozymes that cleave mRNA at site specific recognition sequences can be used to destroy MC4-R mRNAs, the use of hammerhead ribozymes is preferred. Hammerhead ribozymes cleave mRNAs at locations dictated by flanking regions that
20 form complementary base pairs with the target mRNA. The sole requirement is that the target mRNA have the following sequence of two bases: 5'-UG-3'. The construction and production of hammerhead ribozymes is well known in the art and is described more fully in Haseloff and Gerlach, 1988,
25 Nature, 334:585-591. There are hundreds of potential hammerhead ribozyme cleavage sites within the nucleotide sequence of human MC4-R cDNA (see FIG. 5). Preferably the ribozyme is engineered so that the cleavage recognition site is located near the 5' end of the MC4-R mRNA; i.e., to
30 increase efficiency and minimize the intracellular accumulation of non-functional mRNA transcripts.

The ribozymes of the present invention also include RNA endoribonucleases (hereinafter "Cech-type ribozymes") such as the one which occurs naturally in Tetrahymena Thermophila
35 (known as the IVS, or L-19 IVS RNA) and which has been extensively described by Thomas Cech and collaborators (Zaug, et al., 1984, Science, 224:574-578; Zaug and Cech, 1986,

Science, 231:470-475; Zaug, et al., 1986, Nature, 324:429-433; published International patent application No. WO 88/04300 by University Patents Inc.; Been and Cech, 1986, Cell, 47:207-216). The Cech-type ribozymes have an eight
 5 base pair active site which hybridizes to a target RNA sequence whereafter cleavage of the target RNA takes place. The invention encompasses those Cech-type ribozymes which target eight base-pair active site sequences that are present in MC4-R.

10 As in the antisense approach, the ribozymes can be composed of modified oligonucleotides (e.g. for improved stability, targeting, etc.) and should be delivered to cells which express the MC4-R in vivo, e.g., hypothalamus. A preferred method of delivery involves using a DNA construct
 15 "encoding" the ribozyme under the control of a strong constitutive pol III or pol II promoter, so that transfected cells will produce sufficient quantities of the ribozyme to destroy endogenous MC4-R messages and inhibit translation. Because ribozymes unlike antisense molecules, are catalytic,
 20 a lower intracellular concentration is required for efficiency.

Endogenous MC4-r gene expression can also be reduced by inactivating or "knocking out" the MC4-r gene or its promoter using targeted homologous recombination (e.g., see Smithies
 25 et al., 1985, Nature 317:230-234; Thomas & Capecchi, 1987, Cell 51:503-512; Thompson et al., 1989 Cell 5:313-321; each of which is incorporated by reference herein in its entirety). For example, a mutant, non-functional MC4-R (or a completely unrelated DNA sequence) flanked by DNA homologous
 30 to the endogenous MC4-r gene can be used, with or without a selectable marker and/or a negative selectable marker, to transfect cells that express MC4-R in vivo. Insertion of the DNA construct, via targeted homologous recombination, results in inactivation of the MC4-r gene. Such approaches are
 35 particularly suited in the agricultural field where modifications to ES (embryonic stem) cells can be used to generate animal offspring with an inactive MC4-R (e.g., see

Thomas & Capecchi 1987 and Thompson 1989, supra). However this approach can be adapted for use in humans provided the recombinant DNA constructs are directly administered or targeted to the required site in vivo using appropriate viral
5 vectors, e.g., herpes virus vectors for delivery to brain tissue; e.g., the hypothalamus and/or choroid plexus.

Alternatively, endogenous MC4-R gene expression can be reduced by targeting deoxyribonucleotide sequences complementary to the regulatory region of the MC4-R gene
10 (i.e., the MC4-R promoter and/or enhancers) to form triple helical structures that prevent transcription of the MC4-R gene in target cells in the body. (See generally, Helene, C. 1991, Anticancer Drug Des., 6(6):569-84; Helene, C., et al., 1992, Ann, N.Y. Acad. Sci., 660:27-36; and Maher, L.J., 1992,
15 Bioassays 14(12):807-15).

5.4.3. DELIVERY OF SOLUBLE MC4-R POLYPEPTIDES

Genetically engineered cells that express soluble MC4-R ECDs or fusion proteins e.g. fusion Ig molecules can be
20 administered in vivo where they may function as "bioreactors" that deliver a supply of the soluble molecules. Such soluble MC4-R polypeptides and fusion proteins, when expressed at appropriate concentrations, should neutralize or "mop up" the native ligand for MC4-R, and thus act as inhibitors of MC4-R
25 activity and induce weight gain.

5.5. PHARMACEUTICAL FORMULATIONS AND METHODS OF TREATING BODY WEIGHT DISORDERS

The invention encompasses methods and compositions for
30 modifying body weight and treating body weight disorders, including but not limited to obesity, cachexia and anorexia. Because a loss of normal MC4-R gene product function results in the development of an obese phenotype, an increase in MC4-R gene product activity, or activation of the MC4-R
35 pathway (e.g., downstream activation) would facilitate progress towards a normal body weight state in obese

individuals exhibiting a deficient level of MC4-R gene expression and/or MC4-R activity.

Alternatively, symptoms of certain body weight disorders such as, for example, cachexia, which involve a lower than
5 normal body weight phenotype, may be ameliorated by decreasing the level of MC4-R gene expression, and/or MC4-R gene activity, and/or downregulating activity of the MC4-R pathway (e.g., by targeting downstream signalling events). Different approaches are discussed below.

10 Agonists of MC4-R can be used to induce weight loss for treating obesity. Antagonists of MC4-R activity can be used to induce weight gain for treating conditions such as anorexia or cachexia. It is not necessary that the compound demonstrate absolute specificity for the MC4-R. For example,
15 compounds which agonize both MC4-R and MC1-R could be used; such compounds could be administered so that delivery to the brain is optimized to achieve weight reduction, and side effects, such as peripheral melanin production resulting in a "tan" may well be tolerated. Compounds which do not
20 demonstrate a specificity for MC4-R can be administered in conjunction with another therapy or drug to control the side-effects that may result from modulating another melanocortin receptor; however, compounds which demonstrate a preference or selectivity for MC4-R over MC3-R are preferred since both
25 receptors are expressed in the brain where localized delivery cannot be used to compensate for lack of receptor specificity.

5.5.1. DOSE DETERMINATIONS

30 Toxicity and therapeutic efficacy of such compounds can be determined by standard pharmaceutical procedures in cell cultures or experimental animals, e.g., for determining the LD₅₀ (the dose lethal to 50% of the population) and the ED₅₀ (the dose therapeutically effective in 50% of the
35 population). The dose ratio between toxic and therapeutic effects is the therapeutic index and it can be expressed as the ratio LD₅₀/ED₅₀. Compounds which exhibit large therapeutic

indices are preferred. While compounds that exhibit toxic side effects may be used, care should be taken to design a delivery system that targets such compounds to the site of affected tissue in order to minimize potential damage to uninfected cells and, thereby, reduce side effects.

The data obtained from the cell culture assays and animal studies can be used in formulating a range of dosage for use in humans. The dosage of such compounds lies preferably within a range of circulating concentrations that include the ED_{50} with little or no toxicity. The dosage may vary within this range depending upon the dosage form employed and the route of administration utilized. For any compound used in the method of the invention, the therapeutically effective dose can be estimated initially from cell culture assays. A dose may be formulated in animal models to achieve a circulating plasma concentration range that includes the IC_{50} (i.e., the concentration of the test compound which achieves a half-maximal inhibition of symptoms) as determined in cell culture. Such information can be used to more accurately determine useful doses in humans. Levels in plasma may be measured, for example, by high performance liquid chromatography.

5.5.2. FORMULATIONS AND USE

Pharmaceutical compositions for use in accordance with the present invention may be formulated in conventional manner using one or more physiologically acceptable carriers or excipients.

Thus, the compounds and their physiologically acceptable salts and solvates may be formulated for administration by inhalation or insufflation (either through the mouth or the nose) or oral, buccal, parenteral or rectal administration.

For oral administration, the pharmaceutical compositions may take the form of, for example, tablets or capsules prepared by conventional means with pharmaceutically acceptable excipients such as binding agents (e.g., pregelatinised maize starch, polyvinylpyrrolidone or

hydroxypropyl methylcellulose); fillers (e.g., lactose, microcrystalline cellulose or calcium hydrogen phosphate); lubricants (e.g., magnesium stearate, talc or silica); disintegrants (e.g., potato starch or sodium starch glycolate); or wetting agents (e.g., sodium lauryl sulphate). The tablets may be coated by methods well known in the art. Liquid preparations for oral administration may take the form of, for example, solutions, syrups or suspensions, or they may be presented as a dry product for constitution with water or other suitable vehicle before use. Such liquid preparations may be prepared by conventional means with pharmaceutically acceptable additives such as suspending agents (e.g., sorbitol syrup, cellulose derivatives or hydrogenated edible fats); emulsifying agents (e.g., lecithin or acacia); non-aqueous vehicles (e.g., almond oil, oily esters, ethyl alcohol or fractionated vegetable oils); and preservatives (e.g., methyl or propyl-p-hydroxybenzoates or sorbic acid). The preparations may also contain buffer salts, flavoring, coloring and sweetening agents as appropriate.

Preparations for oral administration may be suitably formulated to give controlled release of the active compound.

For buccal administration the compositions may take the form of tablets or lozenges formulated in conventional manner.

For administration by inhalation, the compounds for use according to the present invention are conveniently delivered in the form of an aerosol spray presentation from pressurized packs or a nebulizer, with the use of a suitable propellant, e.g., dichlorodifluoromethane, trichlorofluoromethane, dichlorotetrafluoroethane, carbon dioxide or other suitable gas. In the case of a pressurized aerosol the dosage unit may be determined by providing a valve to deliver a metered amount. Capsules and cartridges of e.g. gelatin for use in an inhaler or insufflator may be formulated containing a powder mix of the compound and a suitable powder base such as lactose or starch.

The compounds may be formulated for parenteral administration by injection, e.g., by bolus injection or continuous infusion. Formulations for injection may be presented in unit dosage form, e.g., in ampoules or in multi-
5 dose containers, with an added preservative. The compositions may take such forms as suspensions, solutions or emulsions in oily or aqueous vehicles, and may contain formulatory agents such as suspending, stabilizing and/or dispersing agents. Alternatively, the active ingredient may
10 be in powder form for constitution with a suitable vehicle, e.g., sterile pyrogen-free water, before use.

The compounds may also be formulated in rectal compositions such as suppositories or retention enemas, e.g., containing conventional suppository bases such as cocoa
15 butter or other glycerides.

In addition to the formulations described previously, the compounds may also be formulated as a depot preparation. Such long acting formulations may be administered by implantation (for example subcutaneously or intramuscularly)
20 or by intramuscular injection. Thus, for example, the compounds may be formulated with suitable polymeric or hydrophobic materials (for example as an emulsion in an acceptable oil) or ion exchange resins, or as sparingly soluble derivatives, for example, as a sparingly soluble
25 salt.

The compositions may, if desired, be presented in a pack or dispenser device which may contain one or more unit dosage forms containing the active ingredient. The pack may for example comprise metal or plastic foil, such as a blister
30 pack. The pack or dispenser device may be accompanied by instructions for administration.

5.6. DIAGNOSIS OF BODY WEIGHT DISORDER ABNORMALITIES

Mutations at a number of different genetic loci have
35 been identified which lead to phenotypes related to body weight disorders. Ideally, the treatment of patients suffering from such body weight disorders will be designed to

target the particular genetic loci containing the mutation. Therefore, diagnostic methods that identify mutations in specific genes related to body weight disorders, such as the MC4-r gene, will permit the treatment of body weight

5 disorders through targeting of the mutated gene.

A variety of methods can be employed for the diagnostic and prognostic evaluation of body weight disorders, including obesity, cachexia and anorexia, and for the identification of subjects having a predisposition to such disorders.

10 Such methods may, for example, utilize reagents such as the MC4-r gene nucleotide sequences and antibodies directed against MC4-r gene products, including peptide fragments thereof. Specifically, such reagents may be used, for example, for: (1) the detection of the presence of MC4-r gene
15 mutations, or the detection of either over- or under-expression of MC4-r gene mRNA relative to the non-body weight disorder state; and (2) the detection of either an over- or an under-abundance of MC4-r gene product relative to the non-body weight disorder state.

20 The methods described herein may be performed, for example, by utilizing pre-packaged diagnostic kits comprising at least one specific MC4-r gene nucleic acid or anti-MC4-r antibody reagent, which may be conveniently used, e.g., in clinical settings, to diagnose patients exhibiting body
25 weight disorder abnormalities.

For the detection of MC4-r mutations, any nucleated cell can be used as a starting source for genomic nucleic acid. For the detection of MC4-r gene expression or MC4-r gene products, any cell type or tissue in which the MC4-r gene is
30 expressed, such as, for example, brain cells, may be utilized.

Nucleic acid-based detection techniques are described, below, in Section 5.6.1. Peptide detection techniques are described, below, in Section 5.6.2.

35

5.6.1. DETECTION OF MC4-r GENE NUCLEIC ACID MOLECULES

Predisposition to body weight disorders can be ascertained by testing any tissue for mutations of the MC4-r gene. For example, a person who has inherited a germline
5 MC4-r mutation would be more likely to develop an obese phenotype. In addition, prenatal diagnosis can be carried out by testing fetal cells, placental cells or amniotic fluid for mutations of the MC4-r gene. Alterations in the MC4-r allele can be detected using any of the methods discussed
10 herein. Mutations within the MC4-r gene can be detected by utilizing a number of techniques.

Nucleic acid from any nucleated cell can be used as the starting point for such assay techniques, and may be isolated according to standard nucleic acid preparation procedures
15 which are well known to those of skill in the art.

DNA may be used in hybridization or amplification assays of biological samples to detect abnormalities involving MC4-r gene structure, including point mutations, insertions, deletions and chromosomal rearrangements. Such assays may
20 include, but are not limited to, Southern analyses, single stranded conformational polymorphism analyses (SSCP), and PCR analyses.

Techniques well-known in the art may be used to scan regions of a selected genome or portion thereof, for any
25 variant or mutation, be it known or unknown. Methods that may be used to detect such variants or mutations in the MC4-r gene include direct sequencing (Maxam & Gilbert, 1980, Methods in Enzymology 65:499-560; Sanger et al., 1977, Proc. Natl. Acad. Sci. 74:5463); resequencing by oligonucleotide
30 arrays (Fodor et al., 1993, Nature 364:555-556); Southern blot or pulsed-field gel (PFGE) analysis (Schwartz et al., 1984, Cell 37:67); single stranded conformation analysis ("SSCA") (Orita et al., 1989, Proc. Natl. Acad. Sci. USA 86:2776-2770); heteroduplex analysis (HA) (Keen et al., 1991,
35 Trends Genet. 7:5); denaturing gradient gel electrophoresis ("DGGE") (Wartell et al., 1990, Nucl. Acids Res. 18:2699-2705; Myers et al., 1985, Nucleic Acid Research 13:3131-

3145); denaturing HPLC (Underhill, P.A., 1997, Proc. Natl. Acad. Sci USA 93:196-200); RNase protection assays (Finkelstein et al., 1990, Genoticks 7:167-172; Kinsler et al., 1991, Science 251:1366-1370; Myers, R.M. et al., 1985, Science 230:1242-1246); allele specific oligonucleotide ("ASO") hybridization (Conner et al., 1983, Proc. Natl. Acad. Sci. 80:278-282; Wallace, R.B., et al., 1979, Nucl. Acids Res. 6:3543-3557; Saiki, R.K. et al., 1989, Proc. Natl. Acad. Sci. USA 86:6230-6234)); oligonucleotide ligation assay ("OLA") (Landegren, U., et al., 1988, Science 241:1077-1080; Tobe, V.O., et al., 1996, Nucl. Acids Res. 24:3728-3732); sequence-specific amplification (Newton, C.R. et al., 1989, Nucl. Acids Res. 17:2503-2516); chemical mismatch cleavage (CMC) (Cotton, R.G.H. et al., 1988, Nucl. Acids Res. 17:4223-4233); enzymatic mismatch cleavage (EMC) (Babon J.J., R. et al., 1995, Nucl. Acids Res. 23:5082-5084; Marshall, R.D. et al., 1995, Nat. Genet. 9:177-183); and the use of proteins which recognize nucleotide mismatches, such as the E. coli mutS protein (Modrich, 1991, Ann. Rev. Genet. 25:229-253).

Diagnostic methods that may be used to detect mutations at the MC4-r locus can be classified into two general categories of use. The first category of diagnostic methods includes those diagnostic methods designed to scan a region for an unknown variant. These diagnostic methods may also be applied to the detection of known variants. The second category of diagnostic methods includes those designed specifically to type previously-identified variants, but are not usually applied to the detection of unknown variants.

Diagnostic methods that may be used to type previously-identified variants may include, but are not limited to, allele-specific oligonucleotide (ASO) hybridization, and oligonucleotide ligation assay (OLA), and sequence-specific amplification.

In one embodiment, allele-specific oligonucleotide hybridization is used to detect a previously-identified variant(s) or allele(s) of MC4-R. Allele-specific oligonucleotide hybridization comprises the separate

hybridization of a pair of oligonucleotides, specific to the previously-identified allele, to PCR-amplified genomic DNA or RNA, under conditions that discriminate between complete matches and single-base mismatches. The pair of
5 oligonucleotides must encompass the variant base. Under the appropriate reaction conditions, the target DNA is not amplified if there is a base mismatch (e.g., a nucleotide substitution caused by a mutation) or a small deletion or insertion, at the 3' end of the primer (Okayama et al, 1989,
10 J. Lab. Clin. Med. 114:105-113; Sommer et al., 1992, BioTechniques 12:82-87).

In a specific embodiment of the invention the following oligonucleotides, or their complement, may be used to identify MC4-R variants. To identify the Ile137Thr mutation
15 the following oligonucleotides may be used:

5'-CACTT-3'
5'-ATCCACTTGC-3'
5'-TGCATCCACTTGCAG-3'
5'-GCTTGCATCCACTTGCAGCC-3'
20 5'-CTTGCTTGCATCCACTTGCAGCCTG-3'
5'-CTCCTTGCTTGCATCCACTTGCAGCCTGCT-3'.

To identify the Val102Ile mutation the following oligonucleotides may be used:

5'-CCATT-3'
25 5'-AAACCATTAT-3'
5'-CAGAAACCATTATCA-3'
5'-GATCAGAAACCATTATCATC-3'
5'-ATGGATCAGAAACCATTATCATCAC-3'
5'-CAAATGGATCAGAAACCATTATCATCACCC-3'.

30 To identify the Thr112Met mutation the following oligonucleotides may be used;

5'-TATGG-3'
5'-AGATATGGAT-3'
5'-TACAGATATGGATGC-3'
35 5'-CAGTACAGATATGGATGCAC-3'
5'-GTACAGTACAGATATGGATGCACAG-3'
5'-ACAGTACAGTACAGATATGGATGCACAGAG-3'.

In another embodiment, an oligonucleotide ligation assay (OLA) is used to discriminate a single base mismatch, through the use of a pair of oligonucleotides that are complementary to two preselected alleles. However, in an oligonucleotide
 5 ligation assay, the two oligonucleotides of the pair are ligated in a template-dependent fashion at the site of the variant base. The template or target sequence is typically a region of the gene encompassing the variant base, and is preferably PCR-amplified from genomic DNA or RNA. Similarly,
 10 as described above, sequence-specific amplification relies on PCR primers designed such that the variant base is located at the 3' end of one of the PCR primers. Thus PCR amplification is dependent on complete annealing of this primer and will not take place if there exists a single-base mismatch.

15 In specific embodiments, the direct sequencing of PCR products that are amplified from genomic DNA or RNA may be accomplished using either fluorescent or radioactive methods well known to those skilled in the art.

In another embodiment, resequencing of these PCR
 20 products is accomplished more rapidly by hybridization, to high-density arrays, of oligonucleotides representing the wild-type sequence of the MC4-R gene (Hattori, M., 1993, Genomics 15:415-417).

In another embodiment, Southern blot pulsed-field gel
 25 (PFGE) analysis can be used to identify those sequence variants that abolish or create novel restriction sites.

In another embodiment, variants are identified by single-stranded conformational analysis (SSCA) by virtue of their effect on the conformation of the DNA molecule.
 30 Regions containing known variants or regions being searched for variants are amplified by PCR. These products are denatured and electrophoresed through polyacrylamide gels under non-denaturing conditions that allow the single-stranded molecule to retain their intrastrand interactions.
 35 Single-base changes affect these interactions and consequently alter the rate of migration of the molecule

through the gel. Thus, variants are identified as fragments of altered mobility.

In another embodiment, a SSCA related method of heteroduplex analysis detects single base-pair mismatches in the sequences of re-annealed double-stranded molecules by detecting the altered conformations of such molecules. Such conformational changes will affect the migration of the re-annealed double-stranded molecules through polyacrylamide gels under non-denaturing conditions.

10 In another embodiment, denaturing gradient gel electrophoresis (DGGE) may be used to identify variants based on the difference in melting temperature between two DNA fragments with a single base-pair difference. Double-stranded molecules are electrophoresed through a
15 polyacrylamide gel containing a gradient of increasing denaturant, e.g. example of denaturant, such that at a defined point, a molecule will begin to denature and migrate more slowly. As with SSCA and HA, variants are identified by their altered mobility in the gel.

20 In another embodiment, denaturing HPLC may be used to reveal variants that alter the conformation of the DNA fragment and thus affect migration rate through chromatographic columns. Some methods of denaturing HPLC involve denaturing and annealing a test DNA or RNA to a
25 control to allow heteroduplexes to form, as in HA analysis. Subsequently chemicals or enzymes are used to cleave one or two strands at or nearby the mismatch. In one embodiment, chemical mismatch cleavage (CMC), which employs osmium tetroxide, hydroxylamine and piperidine, is used to cleave
30 one or both strands.

In another embodiment, enzymatic mismatch cleavage (EMC), using mismatch-cleavage enzymes such as T4 endonuclease VII, is used to cleave one or both strands.

In another embodiment, RNase protection assays are used
35 to detect an RNA:RNA mismatch. RNase protection assays exploit the ability of RNase A to cleave RNA:RNA mismatches. Amplified DNA from genomic DNA or RNA is reverse transcribed

into cRNA. The test sample cRNA is annealed to a control wild-type cRNA. Sequence variants may then be detected as mismatches between the two cRNA molecules that are cleaved by RNase. Cleavage is revealed by electrophoretic sizing of the 5 products.

Among the MC4-r nucleic acid sequences which are preferred for such hybridization and/or PCR analyses are those which will detect the presence of the MC4-r gene mutations described, below, in Section 8.2.

10 The level of MC4-r gene expression can also be assayed. For example, RNA from a cell type or tissue known, or suspected, to express the MC4-r gene, such as brain, may be isolated and tested utilizing hybridization or PCR techniques such as are described, above. The isolated cells can be
15 derived from cell culture or from a patient. The analysis of cells taken from culture may be a necessary step in the assessment of cells to be used as part of a cell-based gene therapy technique or, alternatively, to test the effect of compounds on the expression of the MC4-r gene. Such analyses
20 may reveal both quantitative and qualitative aspects of the expression pattern of the MC4-r gene, including activation or inactivation of MC4-r gene expression.

In one embodiment of such a detection scheme, a cDNA molecule is synthesized from an RNA molecule of interest
25 (e.g., by reverse transcription of the RNA molecule into cDNA). A sequence within the cDNA is then used as the template for a nucleic acid amplification reaction, such as a PCR amplification reaction, or the like. The nucleic acid reagents used as synthesis initiation reagents (e.g.,
30 primers) in the reverse transcription and nucleic acid amplification steps of this method are chosen from among the MC4-r gene nucleic acid reagents described in Section 5.1. The preferred lengths of such nucleic acid reagents are at least 9-30 nucleotides. For detection of the amplified
35 product, the nucleic acid amplification may be performed using radioactively or non-radioactively labeled nucleotides. Alternatively, enough amplified product may be made such that

the product may be visualized by standard ethidium bromide staining or by utilizing any other suitable nucleic acid staining method.

Additionally, it is possible to perform such MC4-r gene expression assays "in situ", i.e., directly upon tissue sections (fixed and/or frozen) of patient tissue obtained from biopsies or resections, such that no nucleic acid purification is necessary. Nucleic acid reagents such as those described in Section 5.1 may be used as probes and/or primers for such in situ procedures (see, for example, Nuovo, G.J., 1992, "PCR In Situ Hybridization: Protocols And Applications", Raven Press, NY).

Alternatively, if a sufficient quantity of the appropriate cells can be obtained, standard Northern analysis can be performed to determine the level of mRNA expression of the MC4-r gene.

5.6.2. DETECTION OF MC4-r GENE PRODUCTS

Antibodies directed against wild type or mutant MC4-r gene products or conserved variants or peptide fragments thereof, may also be used as body weight disorder diagnostics and prognostics, as described herein. Such diagnostic methods, may be used to detect abnormalities in the level of MC4-r gene expression, or abnormalities in the structure and/or temporal, tissue, cellular, or subcellular location of MC4-r gene product. Antibodies, or fragments of antibodies, such as those described below, may be used to screen potentially therapeutic compounds in vitro to determine their effects on MC4-r gene expression and MC4-r peptide production. The compounds which have beneficial effects on body weight disorders, such as obesity, cachexia and anorexia, can be identified, and a therapeutically effective dose determined.

In vitro immunoassays may also be used, for example, to assess the efficacy of cell-based gene therapy for body weight disorders, including obesity, cachexia and anorexia. Antibodies directed against MC4-r peptides may be used in

vitro to determine the level of MC4-r gene expression achieved in cells genetically engineered to produce MC4-r peptides. Such analysis will allow for a determination of the number of transformed cells necessary to achieve
5 therapeutic efficacy in vivo, as well as optimization of the gene replacement protocol.

The tissue or cell type to be analyzed will generally include those which are known, or suspected, to express the MC4-r gene, such as, for example, brain cells. The protein
10 isolation methods employed herein may, for example, be such as those described in Harlow and Lane (Harlow, E. and Lane, D., 1988, "Antibodies: A Laboratory Manual", Cold Spring Harbor Laboratory Press, Cold Spring Harbor, New York), which is incorporated herein by reference in its entirety. The
15 isolated cells can be derived from cell culture or from a patient. The analysis of cell taken from culture may be a necessary step in the assessment of cells to be used as part of a cell-based gene therapy technique or, alternatively, to test the effect of compounds on the expression of the MC4-r
20 gene.

Preferred diagnostic methods for the detection of wild-type or mutant MC4-r gene products or conserved variants or peptide fragments thereof, may involve, for example, immunoassays wherein the MC4-r gene products or conserved
25 variants or peptide fragments are detected by their interaction with an anti-MC4-r gene product-specific antibody.

For example, antibodies, or fragments of antibodies, such as those described, above, in Section 5.3, useful in the
30 present invention may be used to quantitatively or qualitatively detect the presence of wild type or mutant MC4-r gene products or conserved variants or peptide fragments thereof. This can be accomplished, for example, by immunofluorescence techniques employing a fluorescently
35 labeled antibody (see below, this Section) coupled with light microscopic, flow cytometric, or fluorimetric detection.

Such techniques are especially preferred if such MC4-r gene products are expressed on the cell surface.

The antibodies (or fragments thereof) useful in the present invention may, additionally, be employed histologically, as in immunofluorescence or immunoelectron microscopy, for in situ detection of wild type or mutant MC4-r gene products or conserved variants or peptide fragments thereof. In situ detection may be accomplished by removing a histological specimen from a patient, and applying thereto a labeled antibody of the present invention. The antibody (or fragment) is preferably applied by overlaying the labeled antibody (or fragment) onto a biological sample. Through the use of such a procedure, it is possible to determine not only the presence of the MC4-r gene product, or conserved variants or peptide fragments, but also its distribution in the examined tissue. Using the present invention, those of ordinary skill will readily perceive that any of a wide variety of histological methods (such as staining procedures) can be modified in order to achieve such in situ detection.

Immunoassays for wild type or mutant MC4-r gene products or conserved variants or peptide fragments thereof will typically comprise incubating a sample, such as a biological fluid, a tissue extract, freshly harvested cells, or lysates of cells which have been incubated in cell culture, in the presence of a detectably labeled antibody capable of identifying wild type or mutant MC4-r gene products or conserved variants or peptide fragments thereof, and detecting the bound antibody by any of a number of techniques well-known in the art.

The biological sample may be brought in contact with and immobilized onto a solid phase support or carrier such as nitrocellulose, or other solid support which is capable of immobilizing cells, cell particles or soluble proteins. The support may then be washed with suitable buffers followed by treatment with the detectably labeled MC4-r gene specific antibody. The solid phase support may then be washed with the buffer a second time to remove unbound antibody. The

amount of bound label on solid support may then be detected by conventional means.

By "solid phase support or carrier" is intended any support capable of binding an antigen or an antibody. Well-
 5 known supports or carriers include glass, polystyrene, polypropylene, polyethylene, dextran, nylon, amylases, natural and modified celluloses, polyacrylamides, gabbros, and magnetite. The nature of the carrier can be either soluble to some extent or insoluble for the purposes of the
 10 present invention. The support material may have virtually any possible structural configuration so long as the coupled molecule is capable of binding to an antigen or antibody. Thus, the support configuration may be spherical, as in a bead, or cylindrical, as in the inside surface of a test
 15 tube, or the external surface of a rod. Alternatively, the surface may be flat such as a sheet, test strip, etc. Preferred supports include polystyrene beads. Those skilled in the art will know many other suitable carriers for binding antibody or antigen, or will be able to ascertain the same by
 20 use of routine experimentation.

The binding activity of a given lot of anti-MC4-r gene product antibody may be determined according to well known methods. Those skilled in the art will be able to determine operative and optimal assay conditions for each determination
 25 by employing routine experimentation.

One of the ways in which the MC4-r gene peptide-specific antibody can be detectably labeled is by linking the same to an enzyme and use in an enzyme immunoassay (EIA) (Voller, A., "The Enzyme Linked Immunosorbent Assay (ELISA)", 1978,
 30 Diagnostic Horizons 2:1-7, Microbiological Associates Quarterly Publication, Walkersville, MD); Voller, A. et al., 1978, J. Clin. Pathol. 31:507-520; Butler, J.E., 1981, Meth. Enzymol. 73:482-523; Maggio, E. (ed.), 1980, Enzyme Immunoassay, CRC Press, Boca Raton, FL.; Ishikawa, E. et al.,
 35 (eds.), 1981, Enzyme Immunoassay, Kigaku Shoin, Tokyo). The enzyme which is bound to the antibody will react with an appropriate substrate, preferably a chromogenic substrate, in

such a manner as to produce a chemical moiety which can be detected, for example, by spectrophotometric, fluorimetric or by visual means. Enzymes which can be used to detectably label the antibody include, but are not limited to, malate-
5 dehydrogenase, staphylococcal nuclease, delta-5-steroid isomerase, yeast alcohol dehydrogenase, alpha-glycerophosphate, dehydrogenase, triose phosphate isomerase, horseradish peroxidase, alkaline phosphatase, asparaginase, glucose oxidase, beta-galactosidase, ribonuclease, urease,
10 catalase, glucose-6-phosphate dehydrogenase, glucoamylase and acetylcholinesterase. The detection can be accomplished by colorimetric methods which employ a chromogenic substrate for the enzyme. Detection may also be accomplished by visual comparison of the extent of enzymatic reaction of a substrate
15 in comparison with similarly prepared standards.

Detection may also be accomplished using any of a variety of other immunoassays. For example, by radioactively labeling the antibodies or antibody fragments, it is possible to detect MC4-r gene peptides through the use of a
20 radioimmunoassay (RIA) (see, for example, Weintraub, B., Principles of Radioimmunoassays, Seventh Training Course on Radioligand Assay Techniques, The Endocrine Society, March, 1986, which is incorporated by reference herein). The radioactive isotope can be detected by such means as the use
25 of a gamma counter or a scintillation counter or by autoradiography.

It is also possible to label the antibody with a fluorescent compound. When the fluorescently labeled antibody is exposed to light of the proper wave length, its
30 presence can then be detected due to fluorescence. Among the most commonly used fluorescent labeling compounds are fluorescein isothiocyanate, rhodamine, phycoerythrin, phycocyanin, allophycocyanin, o-phthaldehyde and fluorescamine.

35 The antibody can also be detectably labeled using fluorescence emitting metals such as ^{152}Eu , or others of the lanthanide series. These metals can be attached to the

antibody using such metal chelating groups as diethylenetriaminepentacetic acid (DTPA) or ethylenediaminetetraacetic acid (EDTA).

The antibody also can be detectably labeled by coupling
 5 it to a chemiluminescent compound. The presence of the chemiluminescent-tagged antibody is then determined by detecting the presence of luminescence that arises during the course of a chemical reaction. Examples of particularly useful chemiluminescent labeling compounds are luminol,
 10 isoluminol, theromatic acridinium ester, imidazole, acridinium salt and oxalate ester.

Likewise, a bioluminescent compound may be used to label the antibody of the present invention. Bioluminescence is a type of chemiluminescence found in biological systems in,
 15 which a catalytic protein increases the efficiency of the chemiluminescent reaction. The presence of a bioluminescent protein is determined by detecting the presence of luminescence. Important bioluminescent compounds for purposes of labeling are luciferin, luciferase and aequorin.

20

6. EXAMPLE: GENERATION OF AN MC4-R DEFICIENT MOUSE

The following example describes the engineering and generation of "knock-out" mice in which the endogenous MC4-r is inactivated. The results show that the knock-out mice
 25 gain weight, thus, demonstrating the role and function of the MC4-R in body weight regulation.

6.1. MATERIALS AND METHODS

6.1.1. IDENTIFICATION OF THE MURINE MC4-R GENE

30 The murine melanocortin 4 receptor (MC4-r) gene was isolated from a mouse strain 129/Sv genomic phage library, obtained from Stratagene, using a human MC4-r probe. The human probe was generated by PCR amplification of MC4-r coding sequences from human genomic DNA using the following
 35 primers:

5'-ATA GTC GAC ATG GTG AAC TCC ACC CAC CGT-3'; and

5'-TAT AAG CTT TTA ATA TCT GCT AGA CAA GTC-3'.

Two positive phage clones containing the MC4-r gene were identified, and the MC4-r locus was subcloned from phage into pBluescript II as an ~5 Kb Hind III fragment, and an ~4.7 Kb Sac I fragment. These subclones were restriction mapped and partially sequenced to produce the map of the MC4-r locus shown in Fig. 2A. In order to inactivate MC4-r, a targeting construct was built which would delete the majority of MC4-r coding sequences following homologous recombination with the endogenous MC4-r locus.

10

6.1.2. GENERATION OF THE TARGETING CONSTRUCT

The MC4-r targeting construct was constructed in the following manner. The 1.4 Kb Eco RI-Ava I fragment of pBR322 was replaced with the following synthetic oligonucleotides:

15 5'-AAT TAG CGG CCG CAG TAT GCA AAA AAA AGC CCG CTC ATT AGG
CGG GCT-3'; and 5'-CCG AAG CCC GCC TAA TGA GCG GGC TTT TTT
TTG CAT ACT GCG GCC GCT-3'.

The resulting plasmid, called pJN1, was digested with Not I and the following oligonucleotides were ligated into the Not

20 I site.

5'-GGC CGG CAT GCA TCA AGC TTA TCT CGA GAT CGT CGA CTA CCA
TGG TAC ATC GAT CAG GTA CCA TCC CGG GGC-3'; and 5'-GGC CGC
CCC GGG ATG GTA CCT GAT CGA TGT ACC ATG GTA GTC GAC GAT CTC
GAG ATA AGC TTG ATG CAT GCC-3'.

25 The resulting plasmid was called pJN2.

The 1.2 Kb Sph I-Hind III fragment 3' of the MC4-r gene (see Fig. 2A) was subcloned into SphI-Hind III digested pJN2 to generate the plasmid MC4-r KO 3' (FIG. 2B). This fragment represents the 3' region of genomic homology in the targeting
30 vector. A 3.4 Kb NcoI-Hind III fragment, including the first approximately 20 nucleotides of the MC4-r gene (see Fig. 2A), was excised as a NcoI-Asp718 fragment from the subclone MC4-r locus. The Asp718 site was derived from pBluescript II polylinker sequences immediately flanking the native Hind III
35 site approximately 3.4 Kb 5' of the MC4-r gene (Fig. 2A). This fragment, which represents the 5' region of genomic homology in the targeting construct, was ligated into NcoI-

Asp 718 digested MC4-r KO 5' to produce MC4-r KO 5'3' (Fig. 2C).

The PGK-neo expression cassette from the plasmid pKJ1 (Tybulewicz et al., Cell 65, 1153-1163, 1991), containing the
 5 neo gene under the transcriptional control of the mouse phosphoglycerate kinase (PGK-1) promoter and the PGK-1 poly(A) addition site, was subcloned as an Eco RI-Hind III fragment into EcoRI-Hind III digested pGEM 7-Zf(+) to generate pGEM 7 (KJ1). The 1.7 Kb fragment containing the
 10 PGK-neo expression cassette was excised by: 1) digestion of pGEM 7 (KJ1) with Xho I, which cuts in the polylinker 5' of the PGK promoter, and blunt end filling of the Xho I site with Klenow polymerase, and 2) digestion with Sca I which cuts within mouse genomic sequence 3' of the PGK
 15 polyadenylation signal. This fragment was ligated into Xho I digested MC4-r KO 5'3' which had also been blunt-ended with Klenow polymerase, to generate the MC4-r targeting vector MC4-r KO 5'3' neo (Fig. 2D). A schematic map of the gene targeting strategy for inactivation of the MC4-r locus with
 20 this vector is shown in Figures 3A-3D.

6.1.3. GENERATION OF TARGETED ES CELLS

The RF-8 ES cell line (obtained from the Gladstone Institute of Cardiovascular Disease, UCSF) was cultured on
 25 SNL76/7 mitotically inactive feeder cells as described in McMahon and Bradley (1990, Cell 62: 1073-1085). For electroporation, cells were trypsinized and resuspended at a concentration of 1.1×10^7 /ml in PBS (Ca^{2+} and Mg^{2+} free; Gibco). An 0.9 ml aliquot (1×10^7 cells) was mixed with
 30 μg of MC4-r KO 5'3' DNA, which had been linearized by Not I digestion, and pulsed at 250V, 500 μF (Bio-Rad Gene Pulser), after which the cells were diluted in culture medium, plated at 1×10^6 per 100 mm plate containing feeder cells, and placed under selection twenty-four hours later in G418
 35 sulfate (400 $\mu\text{g}/\text{ml}$ powder, Gibco) for 6 days. 427 G418 resistant clones were picked, dissociated with trypsin and divided into one well each of two 96-well plates. Upon

confluence, ES cells were frozen in one of the 96-well plates as described by Ramirez-Solis et al., (Methods in Enzymology, vol. 225, Wassarman, P.M., DePamphilis, M.L. (eds). Academic Press, p. 855-878, 1992) and expanded into a 24 well plate.

5 Upon confluence, DNA was prepared for Southern blot analysis.

Genomic DNA was prepared *in situ* from ES cells in 24 well plates by the procedure of Laird et al. (1991, Nucleic Acids Research 19: 4293). To screen for homologous recombination between the vector and the endogenous MC4-r
10 locus approximately 20 µg of genomic DNA was digested with Apa I, electrophoresed through a 1% agarose gel, transferred to Hybond N⁺ membrane (Amersham), and hybridized with the ³²P radiolabeled Sac I-Sph I probe (see FIG. 3A).

15 6.1.4. GENERATION OF MC4-R DEFICIENT MICE

Clone 155 was injected into C57BL/6J blastocysts to generate chimeric mice as described in (Bradley, A. In Robertson, E.J. (ed) Teratocarcinomas and Embryonic Stem Cells. IRL Press, Oxford, England, p. 113-151, 1987). Male
20 chimeras were bred with C57BL/6J females, and agouti offspring (representing germline transmission of the ES genome) were screened for the presence of the targeted MC4-r gene by Southern blot hybridization of Apa I as well as Nco I digested tail DNA using the probe shown in FIG. 3A.

25 Offspring heterozygous for the mutation were identified by either the presence of a 7.6 Kb Apa I band in addition to the wild type 2.2 Kb band or the presence of a 1.9 Kb Nco I band in addition to the wild type bands of 2.6 Kb and 2.8 Kb (FIG. 3D).

30 Heterozygous mice were interbred and offspring generated by these matings were screened by Southern blot hybridization of Apa I as well as Nco I digested tail DNA. Mice homozygous for the deleted MC4-r gene were identified by the absence of the wild type 2.2 Kb Apa I band and 2.8 Kb Nco I band, and
35 presence of the targeted 7.6 Kb Apa I band and 1.9 Kb Nco I band. To verify deletion of the MC4-r gene, the Apa I digested and Nco I digested blots were stripped and re-probed

with the human MC4-r coding sequence. No hybridizing bands were observed in the DNA from mice homozygous for the MC4-r mutation, verifying the absence of the MC4-r gene in these mice.

5

6.1.4 WEIGHT AND LENGTH MEASUREMENTS

Weight gain was regularly measured, beginning at 3-4 weeks of age, using a Sartorius model #14800 P balance.

Length was measured by manual immobilization and extension of
10 the mouse to its full length, always by the same individual, and measurement of the nose to anus distance in centimeters.

6.1.5. FOOD CONSUMPTION

Food intake was measured for two A^y, two C57BL/6J, four
15 MC4-R homozygous mutants, and four wild type F2 controls, each housed two to a cage. The mice were housed for at least a week before any measurements were taken. Over a two week period, a sufficient amount of food for the week was then weighed and provided to the mice *ad libitum*. Each weekday
20 morning the remaining food was measured, for a total of eight measurements. Cages were carefully monitored for spillage, which was negligible. The A^y and C57BL/6J mice were 9 weeks of age at the time measurement of food consumption was initiated; both the four MC4-R deficient mice and the F2
25 controls were each 15, 15, 17.5 and 20.5 weeks of age.

6.1.6. SERUM ANALYSIS

For glucose, insulin and leptin measurements, blood was collected by retroorbital sinus puncture from animals
30 provided with food and water *ad libitum*. Mice were handled regularly (three times per week for several weeks) prior to bleeding to minimize stress, and cages were singly moved to a separation location at the time of bleeding. For measurement of glucose levels, 5 μ l of serum was analyzed in a YSI
35 Model 27 glucose analyzer (Yellow Springs Instrument Company, Inc.) using a glucose oxidase assay. Results are expressed as mg/dl. The range of detection is 0-500 mg/dl, with a

coefficient of variation of <1%. Serum insulin concentration was measured in duplicate in a 10 μ l volume by a specific competitive protein binding assay using rat insulin as the standard. Results are expressed as ng/ml. The range of
5 detection is 0.1-25 ng/ml with a coefficient of variation of <10%. Leptin was measured in duplicate in 20 μ l of serum using a radioimmunoassay kit to mouse leptin with recombinant mouse leptin as the standard (Linco Research, Inc.).

For serum corticosterone measurements, mice were housed
10 at three animals per cage with food and water *ad libitum*. To prevent stress-mediated elevation of corticosterone levels mice were handled 2-3 times/day for three days prior to drawing blood. Cages were brought one at a time into a separate room, mice were weighed and then held as if blood
15 were to be drawn. On the fourth day mice were handled similarly, and blood drawn between 8:00 and 9:00 A.M. within 30 sec of handling. Cages were not returned to the housing room until all the samples had been obtained. Blood was obtained by snipping the tail tip and collecting blood into a
20 Multivette S Gel tube (Sarstedt). Tubes were placed on ice for 20-40 minutes and centrifuged 3-4 minutes at 14,000 rpm to separate the serum. Two one μ l aliquots of serum from each sample were then assayed for corticosterone levels using an ImmuChem Double Antibody Corticosterone 125I RIA kit (ICN
25 Biomedicals, Inc.)

6.1.7. HISTOLOGY

For *in situ* hybridization analysis of POMC gene expression, wild type, heterozygous, and homozygous mutant
30 mice were maintained under a 12-h light, 12-h dark cycle at constant temperature. Food (Purina mouse chow) and water were provided *ad libitum*. Anesthetized (avertin) animals were sacrificed between 1500 and 1700 hrs. before lights out via cardiac puncture and perfusion with saline (20 mls) and
35 then 50 mls of ice-cold fixation buffer (4% paraformaldehyde in borate buffer, pH 9.5). Whole brains were rapidly removed and then post-fixed overnight in 10% sucrose/fixative buffer.

Blocked hypothalamic sections were frozen in powdered dry ice and then stored at -80°C prior to sectioning.

Antisense POMC probe was prepared by linearizing the plasmid mPOMCE3ribo (kindly provided by Dr. Malcolm Low), containing exon 3 of the mouse POMC gene, with Nco I. [35S] cRNA probes were prepared by transcribing 1 μg of each linearized DNA with T7 DNA polymerase for 1 hr at 37°C as described (Promega). Hypothalamic brain blocks were mounted on a frozen stage and serially sectioned into 4 series of 20- μM slices with a sliding microtome. Sections were prepared and hybridized for 20 h at 58°C with ^{35}S -labeled probes (5×10^6 cpm/ml) in 65% formamide, 0.26 M NaCl, 1.3 x Denhardt's solution, 1.3 mM EDTA, 13% dextran sulfate, 13 mM Tris, pH 8. Sections were then digested with RNase (20 $\mu\text{g}/\text{ml}$) for 30 min at 37°C , and then desalted in a series of washes from 4 x SSC/1 mM DTT to a final stringency of 0.1 x SSC/1 mM DTT at 65°C for 30 min. Sections were dehydrated in ascending ethanol, vacuum dried at room temp for 30 min, and then exposed to Dupont Cronex film for several days. Dried slides were then dipped in NTB-2 emulsion (Kodak), and developed after 6 days.

6.2. RESULTS

6.2.1. GENERATION OF MC4-R DEFICIENT MICE

The murine MC4-R gene consists of approximately 1 kb of coding sequence contained within a single exon (Figure 1A). A targeting vector was designed to delete virtually all MC4-R coding sequence following homologous recombination with the locus in embryonic stem (ES) cells. As shown in Figure 1A, the vector consists of a total of approximately 4.5 kb of strain 129/Sv mouse genomic DNA flanking a deletion of 1.5 kb. This deletion extends from the Nco I site located approximately 20 nucleotides downstream of the MC4-R initiation codon to the Hind III site situated approximately 0.5 kb 3' of the gene. The deleted MC4-R sequences have been replaced by the neo gene under the control of the phosphoglycerate kinase-1 (PGK-1) promoter.

A total of 809 G418-resistant colonies were screened for homologous recombination by Southern blot hybridization of Apa I digested genomic DNA with the flanking probe shown in Figure 3A. One clone showed the predicted 7.6 kb targeted
5 Apa I DNA fragment in addition to the expected 2.2 kb wild type fragment. Injection of this clone into C57BL/6J blastocysts produced several male chimeras which, when bred to C57BL/6J females, transmitted the targeted MC4-R allele to their F1 129/B6 offspring. F1 heterozygotes were interbred
10 and their offspring genotyped by Southern blot hybridization of Apa I or Nco I digested tail DNA with the flanking probe. As described above, Apa I digestion generates a wild type fragment of 2.2 kb and a targeted fragment of 7.6 kb (note that this 7.6 kb is distinct from a background band of
15 slightly lower molecular weight which is present in all samples; Figure 3E). Nco I digestion generates two wild type fragments of 2.7 and 2.9 kb, since the Nco I site is situated within the sequences recognized by the flanking probe (Figure 3). The 2.7 kb Nco I fragment represents genomic
20 sequences extending 3' of the probe which are unaffected by MC4-R targeting, whereas the 2.9 kb band includes the MC4-R gene sequences. Following targeting, this latter fragment is reduced to a 2 kb band diagnostic of the mutated MC4-R allele. As shown in Figure 3E, heterozygous intercrosses
25 produced homozygous mutant, heterozygous and wild type F2 progeny. To verify deletion of the MC4-R gene in homozygous mutants, the filters were stripped and rehybridized with an MC4-R probe. No MC4-R hybridization was detected in homozygous mutant mice, whereas the predicted 2.2 kb and
30 5.1 kb Apa I bands (Apa I cuts within the MC4-R gene generating two MC4-R-containing fragments; see Figure 3A) and 2.9 kb Nco I fragment were observed in both heterozygous and wild type littermates (Figure 3E).

6.2.2. BODY WEIGHT AND SIZE OF MC4-R DEFICIENT MICE

F2 animals were maintained on a chow diet *ad libitum* and their weights monitored regularly. The weights of MC4-R deficient mice and their wild type littermates were largely indistinguishable for the first 4 weeks of life. However, by approximately 5 weeks of age most of the homozygous mutants, both males and females, were heavier than their wild type siblings of the same sex, and by 7 weeks of age all of the null mutants were heavier than the controls (Figure 4A and 4C). By 15 weeks of age, homozygous mutant females were on average twice as heavy as their wild type siblings, while homozygous mutant males were approximately 50% heavier than wild type controls. Weight gain for both males and female mutant mice appeared to be approaching a plateau by about 24 weeks of age at which time the weight of female null mice averaged approximately 63 grams (n=3), and males averaged approximately 65 grams (n=8). Mice heterozygous for MC4-R deletion showed a weight gain intermediate to that seen in wild type and homozygous mutant sibs (Figure 4B and 4D), demonstrating a gene dosage effect of MC4-R ablation on body weight regulation.

One of the distinguishing characteristics of the obese yellow phenotype is an increase in skeletal growth.

Typically, *A^y* mice are on average approximately 5% longer than their wild type siblings (Castle, 1941, Genetics 26:177191; Carpenter and Mayer, 1958, Am. J. Physiol. 193:499-504). To determine whether mice lacking the MC4-R exhibit enhanced linear growth, body length measurements of F2 progeny were taken at approximately 19 weeks of age (between 132-138 days). As shown in Figure 6, MC4-R deficient mice are significantly longer than wild type controls. The mean length of homozygous mutant females is increased approximately 11% relative to wild type F2 mice, and heterozygous females are approximately 7% longer than controls. Male homozygotes and heterozygotes are approximately 8% and 2.5% longer than controls, respectively.

6.2.3. FOOD CONSUMPTION

To determine whether food consumption was increased in mice lacking the MC4-R , homozygous mutant females and wild type F2 controls were monitored for food intake over a 2 week period. A^y mutants, on a C57BL/6J background, and C57BL/6J controls were also monitored. As previously documented (Frigeri et al., 1988, Endocrinology 113:2097-2105; Shimizu et al., 1989, Life Sciences 45:543-552), A^y mice were hyperphagic, eating 36% more than C57BL/6J controls. Similarly, absence of the MC4-R also resulted in a significant increase (46%) in food consumption over wild type F2 controls (Figure 7).

6.2.4. SERUM ANALYSIS

Blood was collected from MC4-R deficient mice and wild type controls over three time intervals (4-8 weeks, 10-14 weeks, 17-23 weeks) and serum assayed for glucose and insulin levels. Serum glucose levels were essentially unchanged in females heterozygous or homozygous for MC4-R deletion, but both heterozygous and homozygous males were hyperglycemic (Figure 8A and 8B). This was first evident for homozygous males at the 10-24 week interval at which time glucose levels were elevated over 2 fold above controls, to 390 mg/dl, but heterozygous mutants showed only a slight elevation of serum glucose at this age. By 17-23 weeks of age, both heterozygous and homozygous male mutant mice showed a doubling of normal serum glucose levels (334 and 361 mg/dl, respectively) relative to controls (156 mg/dl).

Both male and female mutant mice were hyperinsulinemic (Figure 8C and 8D). Nine fold and 5 fold increases in insulin levels were evident in the sera of homozygous mutant females and males, respectively, at 4-8 weeks of age. These levels increased dramatically over time, such that by 17-23 weeks of age the mean concentration of insulin in the serum of homozygous mutant females was approximately 65 ng/ml, and for males approximately 130 ng/ml, representing approximately 60 and 14 fold increases, respectively, over insulin levels

in F2 wild type controls. Heterozygous mutants were also hyperinsulinemic, although less so than homozygous mutants. For both male and female heterozygotes, a significant difference in insulin levels relative to controls was first
5 observed at the 10-14 week interval; by 17-23 weeks mean insulin levels of heterozygotes were elevated to approximately 10 ng/ml (females) and 85 ng/ml (males).

In addition to glucose and insulin, serum leptin and corticosterone levels were also determined. Leptin levels
10 are elevated in A^y mice (Maffei et al., 1995, Nat. Med. 1:1155-1161; Mizuno et al., 1996, Proc. Natl. Acad. Sci. 93:3434-3438), indicating that the syndrome does not result from defects in leptin production. Consistent with postulated role of the hormone in signaling fat depot levels
15 (Campfield et al., 1995, Science 269:546-549; Halaas et al., 1995, Science 269:543-546; Pelleymounter et al., 1995, Science 269:540-543), leptin is also elevated in MC4-R deficient mice (Figure 8E and 8F). At 4-8 weeks of age leptin was elevated 4.5 fold and 1.5 fold in the serum of
20 female and male homozygous mutants, respectively, relative to wild type controls. By 17-23 weeks of age serum leptin levels in females had reached approximately 97 ng/ml, in males approximately 58 ng/ml, representing increases of 6.5 and 2.5 fold, respectively. Heterozygous mice, for the most
25 part, showed leptin levels intermediate between that observed for wild type mice and homozygous mutants.

Since glucocorticoids can profoundly effect weight homeostasis and somatic growth, basal serum corticosterone was measured in three sets of sex-matched littermates, each
30 containing a wild-type, heterozygous, and homozygous mutant animal (Figure 9). No effect of MC4-R gene knockout on basal corticosterone levels was detected.

6.2.5. POMC GENE EXPRESSION

35 To assess whether the observed effects of MC4-R deletion on weight homeostasis could be attributed to the induction of compensatory changes in the sole known source of ligand for

the MC4-R, the POMC gene, central POMC gene expression was examined in wild type mice, mice heterozygous for MC4-R deletion and homozygous mutants by in situ hybridization (FIG.10A-10F). No new sites of POMC gene expression and no
5 consistent change in the levels of POMC mRNA in its primary site of expression, the arcuate nucleus of the hypothalamus, were detected by this assay. In addition, no gross neuroanatomical defects were observed in thionin-stained brain sections from heterozygous or homozygous mutant MC4-R
10 deficient animals by histological analysis (FIG. 10A-10C).

7. EXAMPLE: AGOUTI PROTEIN BINDS DIRECTLY TO MC1-R AND MC4-R

The following example describes experiments
15 demonstrating that the Agouti protein binds directly to the melanocortin receptors.

7.1. MATERIAL AND METHODS

Human melanocortin receptor 4 (hMC4-r) cDNA, under the control of the CMV promoter, was transfected into the 293
20 cell line, and stable clones were selected (293/MC4-R). The stable clones were tested for reduction in intracellular cAMP levels in the presence of 5nM agouti protein.

COS-7 cells were transfected with hMC1-r or hMC4-r by the DEAE-Dextran method. A plasmid containing the Adenovirus
25 VA1 and VA2 RNA genes was used to co-transfect the COS cells to enhance transient protein expression by increasing translational initiation. The MC4-r and the VA1/2 cDNA plasmids were used at a ratio of 10 to 1. Control plates received the VA1/2 plasmid alone. 48 hours post-
30 transfection, the cells were rinsed and culture supernatant containing 15nM of AP-Ag was added. AP-Ag is a truncated agouti protein, containing the cysteine-rich domain tagged with the alkaline phosphatase at its N-terminal. Binding of
35 AP-Ag to transfected cells proceeded at room temperature for 90 minutes with gentle rocking. The cells were then washed 7

times before fixing and color development using NBT/BCIP substrate.

7.2. RESULTS

5 When 5 nM agouti protein was added to the 293/MC4-R line, an 18% reduction of intracellular cAMP level, relative to the parental 293 cell line, was observed. The results indicate that MC4-R mediates the agouti-triggered decrease of intracellular cAMP level and confers agouti response to 293
10 cells.

 N-terminal truncated agouti protein, containing only the cysteine-rich C-terminal domain, retains the antagonizing activity of the full-length agouti. A truncated agouti protein, containing only the cysteine-rich domain and tagged
15 with the alkaline phosphatase at its N-terminal, was used to assay the direct binding between the agouti protein and the MC1 and MC4 receptors in COS7 cells.

 The transfection efficiency, as monitored by β -galactosidase reporter plasmid, typically was 12-16%. 10-13%
20 of the MC1-r transfected and 3-4% of the MC4-r transfected COS7 cells bound the agouti protein as determined by AP staining. The observed difference in percentage of positive cell between the MC1-r and MC4-r transfected COS7 cells could be attributed to differences in binding affinity and/or
25 expression level.

 To assess the affinity of the agouti protein for the MC1-R receptor, a Scatchard Analysis was performed on MC1-r transfected COS7 cells using culture supernatant containing up to 30 nM AP-Ag. The Kd has been estimated at 20-30nM
30 range.

7.3. DISCUSSION

 The dominant agouti alleles that give rise to obesity result from constitutive deregulated synthesis of wild-type
35 agouti protein throughout the animal, and presumably accounts for the other characteristics of the pleiotropic obesity syndrome such as hyperphagia, hyperinsulinemia, and

hyperglycemia. One possible mechanism by which ectopic agouti expression induces obesity is aberrant antagonism of melanocortin receptors, such as MC4-R, expressed in regions of the brain known to be involved in regulating feeding.

5 The data presented herein demonstrates that the Agouti protein binds directly to MC4-R. Furthermore, as described in Example 6, *supra*, transgenic mice lacking the MC4-R produce an obesity syndrome that strikingly resembles the agouti syndrome. The recapitulation of many of the features
10 of the agouti syndrome in MC4-R deficient mice demonstrates that antagonism of melanocortin signaling via MC4-R is the primary cause of the agouti obesity syndrome.

8. EXAMPLE: IDENTIFICATION AND FUNCTIONAL
15 CHARACTERIZATION OF HUMAN MELANOCORTIN 4
RECEPTOR Ile137Thr MUTANT

Several mutant genes have been identified that cause obesity in mouse; in human, however, only a mutation in $\beta 3$ adrenergic receptor gene has been inconclusively associated with obesity. The identification of the MC4-R Ile137Thr
20 mutation in obese human subject and the finding of its impaired signaling support MC4-R as a causative genetic factor contributing to human obesity, and validate the receptor as a potential drug target.

25 8.1. MATERIALS AND METHODS

8.1.1. DETECTION OF MUTANT MC4-R RECEPTOR

Human genomic DNA isolated from total white blood cells was amplified by PCR using the following primer pairs:

MC4f1b	5'-TGTAACGACGGCCAGTCTGACCCAGGAGGTAAATC-3'
30 MC4r1b	5'-CAGGAAACAGCTATGACCGCTGCAGATGAAAAGTACATG-3'
MC4f2b	5'-TGTAACGACGGCCAGTTGCTACGAGCAACTTTTCTC-3'
MC4r2b	5'-CAGGAAACAGCTATGACCGGTACTGGAGAGCATAGAAG-3'
MC4f3	5'-TGTAACGACGGCCAGTTGGTGAGCGTTTCAAATGGAT-3'
MC4r3	5'-CAGGAAACAGCTATGACCGAGCCAGCATGGTGAAGAAC-3'
35 MC4f4	5'-TGTAACGACGGCCAGTATCTTCTATGCTCTCCAGTAC-3'
MC4r4	5'-CAGGAAACAGCTATGACCTTCTGAGGACAAGAGATGTAG-3'

MC4f5b 5'-TGTAACGACGGCCAGTTTCTCTCTATGTCCACATGTTC-3'
 MC4r5b 5'-CAGGAAACAGCTATGACCGAGTGAAAAAGTCTCTTATGCATG-3'

The following PCR amplification conditions were used:

The 25 μ L PCR reactions contained a buffer (10 mM Tris-HCl, pH 8.3, 50mM KCl, 1.5 mM MgCl₂), the four dNTPs at 100 μ M each, 1 μ M each primer, 0.5U Taq polymerase, and 50-100 ng genomic DNA. The fragments were amplified in a touchdown PCR (94°C 30 sec, 65°C-55°C 30 sec (-1°C/cycle), 72° 40 sec), followed by 30 cycles of 94°C 30 sec, 55°C 30 sec, and 72°C 40 sec.

10 The amplicons were treated with Exonuclease I to remove residual single-stranded primers and Shrimp Alkaline Phosphatase to remove unincorporated dNTPs [Template Purification Kit for Sequencing, Amersham US70995]. The purified fragments were then digested with restriction
 15 enzymes MspI and HinfI to yield fragments smaller than 250bp, sizes better suited to analysis by SSCP.

The digested PCR products were diluted 1:9 in loading buffer (95% formamide, 20 mM EDTA, 0.05% bromphenol blue, 0.05% xylene cyanol), heat denatured at 98°C for 2 minutes,
 20 and snap-cooled in an ice slurry. 2-3 μ L are loaded on a 10% acrylamide gel (50:1 acrylamide:bis-acrylamide) with 10% glycerol and run at 25 watts for 4 hours at 4°C. The gel was stained with SYBR Green I and II to detect both single- and double-stranded DNA fragments, and visualized on a
 25 fluorimager.

8.1.2. RECOMBINANT EXPRESSION OF MUTANT MC4-R

Genomic DNA containing the MC4-R wild type and MC4-R Ile137Thr variant were used as templates for a PCR
 30 amplification reaction. Primers flanking the MC4-R coding region were used to PCR the entire MC4 including the MC4-R Ile137Thr mutation. PCR primers and conditions were as follows:

HMC4 upper primer 5'-CGTAGGATCCATGGTGAAGTCCACCCACCTG-3'
 35 HMC4 lower primer 5'-AGCCTCGAGTTAATATCTGCTAGACAAGTC-3'

PCR conditions:

96 C for 15 minutes; 94 C for 1 minute; 55 C for 1 minute;

73 C for 2 minutes for 35 cycles; 73 C 10 minutes; 4 C. The resultant 1 kb PCR fragments were subsequently cloned into pCDNA3 (Invitrogen) and sequenced to confirm the correct DNA sequence.

5 Expression vectors containing human MC4-R wildtype and I137T mutant cDNAs, respectively, were transfected into 293T cells (HEK 293 cells expressing SV40T antigen) using Lipofectamin (BRL). 48 hours later, transfected cells were plated into 96 well plates. After an additional 24 hours,
10 the transfected cells were incubated at 37°C for 15 minutes (or at room temperature for 1 hour) with various melanocortins (BACHEM). Intracellular cAMP levels were then determined using a SPA-based assay (Amersham).

To monitor and normalize the transfection efficiency of
15 the wildtype and mutant cDNAs, an expression vector containing β galactosidase gene were always co-transfected with the MC4-R expression vectors (β galactosidase and MCR-R cDNA at a ratio of 1:9). β galactosidase assay performed 72 hours post-transfection confirmed that the wildtype and
20 I137T mutant MC4-Rs had the same transfection efficiency.

8.2. RESULTS

216 unrelated individuals were screened for sequence variation within the coding region of the MC4R gene. The 216
25 individuals comprised of 96 extreme obese as determined by body mass index (BMI>50), 24 obese (BMI:30-50), 18 intermediates (BMI 25-30), 54 leans (BMI,25) and 24 polycystic ovary syndrome (PCOS) patients. 3 amino acid variants have been found in MC4R in this sample. The three
30 variants are Val102Ile (G to A; see FIG. 12A-B), Ile137Thr (T to C; see FIG. 11A-B) and Thr112Met (C to T; see FIG. 13A-B).

The Val102Ile substitution was found amongst all categories of BMI within the sample. The following individuals were heterozygous for this variant: 2 extreme
35 obese (BMI=74.2; BMI=57.2), 2 obese (BMI=43; BMI=26), 2 leans (BMI=22.5; BMI=21).

The Ile137Thr variant was only found once in an extreme obese person (BMI=57.3). This individual is heterozygous for this variant. The substitution of a threonine (polar) for an isoleucine (non-polar) amino acid may have an effect on the
 5 receptor. It is possible that this substitution diminishes the activity of the MC4 receptor contributing to the obesity in this patient.

The Thr112Met variant was only found once (BMI=17.9). This individual is heterozygous for this variant. The
 10 substitution of a methionine (non-polar) for an threonine (polar) amino acid may have an effect on the receptor. - It is possible that this substitution increases the activity of the MC4 receptor contributing to the leanness of this individual.

In order to test whether the Ile137Thr variant was able
 15 to function normally, the activity of the Ile137Thr mutant receptor was compared to a wild-type receptor in a signaling assay. Figure 14 compares the response to five endogenous melanocortins, α -MSH (alpha), β -MSH (beta), γ 1-MS (gamma1), γ 2-MSH (gamma2), and ACTH.

20 The results demonstrate the impaired signaling of the Ile137Thr mutant receptor as measured by cAMP induction in the presence of various agonists. Compared with the wildtype receptor, the mutant has much lower maximum activation, i.e. lower maximum cAMP level achieved; and it generally has
 25 higher EC50, i.e., higher agonist concentration required to reach half maximum activation. The mutant receptor is not totally inactive in the in vitro assay; but it is marginally active only in the presence of very high agonist concentration that may not be reached under physiological
 30 conditions in vivo.

The present invention is not to be limited in scope by the specific embodiments described which are intended as single illustrations of individual aspects of the invention, and functionally equivalent methods and components are within
 35 the scope of the invention. Indeed various modifications of the invention, in addition to those shown and described herein will become apparent to those skilled in the art from

the foregoing description and accompanying drawings. Such modifications are intended to fall within the scope of the appended claims.

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WHAT IS CLAIMED IS:

1. A method for identifying compounds that regulate body weight, comprising:

- (a) contacting a test compound with a cell which
5 expresses a functional melanocortin 4-receptor, and
- (b) determining whether the test compound activates the melanocortin 4-receptor,

in which test compounds that activate the melanocortin 4-receptor are identified as compounds for inducing weight
10 loss.

2. A method for identifying compounds that regulate body weight, comprising:

- (a) contacting a melanocortin peptide in the presence
15 and absence of a test compound with a cell which expresses a functional melanocortin 4-receptor, and
- (b) determining whether the test compound inhibits the melanocortin peptide induced activation of the melanocortin 4-receptor,

20 in which test compounds that inhibit activation of the melanocortin 4-receptor are identified as compounds for inducing weight gain.

3. The method of Claim 1 or 2 in which activation of the
25 melanocortin 4-receptor is determined by measuring induction of cAMP.

4. The method of Claim 3 in which the cell further contains a reporter gene operatively associated with a cAMP responsive
30 element, and induction of cAMP is indicated by expression of the reporter gene.

5. The method of Claim 4 in which the reporter gene is alkaline phosphatase, chloramphenicol acetyltransferase,
35 luciferase, glucuronide synthetase, growth hormone, or placental alkaline phosphatase.

6. The method of Claim 2 in which the melanocortin peptide is α -MSH.

7. A method for identifying compounds that regulate body weight, comprising:

- (a) contacting a test compound with a melanocortin 4-receptor, and;
- (b) determining whether the test compound interacts with the melanocortin 4-receptor,

10 in which test compounds that interact with the melanocortin 4-receptor are identified as compounds that regulate body weight.

8. A method for identifying compounds that regulate body weight, comprising:

- (a) contacting a melanocortin peptide in the presence and absence of a test compound with a melanocortin 4-receptor; and
- (b) determining whether the test compound inhibits the interaction of the melanocortin peptide with the melanocortin 4-receptor,

in which test compounds that inhibit the interaction of the melanocortin peptide with the melanocortin 4-receptor are identified as compounds that regulate body weight.

25

9. The method according the Claim 7 or 8 in which the melanocortin 4-receptor is contained in an isolated membrane or is recombinantly expressed.

30 10. The method according to Claim 8 in which the melanocortin peptide is α MSH.

11. A method for identifying compounds that regulate body weight, comprising:

- 35 (a) contacting a test compound with a cell or cell lysate containing a reporter gene operatively

associated with an melanocortin 4-receptor
regulatory element; and

(b) detecting expression of the reporter gene product.

5 12. A method for identifying compounds that regulate body
weight comprising:

(a) contacting a test compound with a cell or cell
lysate containing melanocortin 4-receptor
transcripts; and

10 (b) detecting the translation of the melanocortin
transcript.

13. A method for the treatment of body weight disorders,
comprising modulating the activity of the melanocortin 4-
15 receptor.

14. A method for the treatment of body weight disorders,
comprising administering an effective amount of a compound
that agonizes or antagonizes the activity of the melanocortin
20 4-receptor.

15. The method of Claim 14 in which the compound activates
the melanocortin 4-receptor and induces weight loss.

25 16. The method of Claim 15 in which the compound is an
agonist or an antibody that binds to and activates the
melanocortin 4-receptor.

17. The method of Claim 14 in which the compound inhibits
30 activation of the melanocortin 4-receptor and induces weight
gain.

18. The method of Claim 17 in which the compound is an
antibody or a soluble extracellular domain of the
35 melanocortin 4-receptor.

19. A method for the treatment of body weight disorders, comprising modulating the activity of the melanocortin 4-receptor gene.
- 5 20. A method of the treatment of body weight disorders, comprising administering an effective amount of a compound that decreases expression of the melanocortin 4-receptor and induces weight gain.
- 10 21. The method of Claim 20 in which the compound is an oligonucleotide encoding an antisense or ribozyme molecule that targets melanocortin 4-receptor transcripts and inhibits translation.
- 15 22. The method of Claim 20 in which the compound is an oligonucleotide that forms a triple helix with the promoter of the melanocortin 4-receptor gene and inhibits transcription.
- 20 23. A pharmaceutical formulation for the treatment of body weight disorders, comprising a compound that activates the melanocortin 4-receptor, mixed with a pharmaceutically acceptable carrier.
- 25 24. The pharmaceutical formulation of Claim 23 in which the compound is a melanocortin peptide agonist or an antibody specific for the melanocortin 4-receptor.
25. A pharmaceutical formulation for the treatment of body
30 weight disorders, comprising a compound that inhibits the selective activation of the melanocortin 4-receptor, mixed with a pharmaceutically acceptable carrier.
26. The pharmaceutical formulation of Claim 25 in which the
35 compound is an antagonist or an antibody specific for the melanocortin 4-receptor.

27. The pharmaceutical formulation of Claim 25 in which the compound is an oligonucleotide encoding an antisense or ribozyme molecule that targets melanocortin 4-receptor transcripts and inhibits translation.

5

28. The pharmaceutical formulation of Claim 25 in which the compound is an oligonucleotide that forms a triple helix with the promoter of the melanocortin 4-receptor gene and inhibits transcription.

10

29. A genetically engineered obese animal in which the melanocortin 4-receptor gene has been inactivated.

30. A transgenic animal which expresses a human melanocortin 15 4-receptor gene.

31. A kit comprising a melanocortin 4-receptor or cells expressing the melanocortin 4-receptor packaged in a container.

20

32. A method for diagnosing body weight disorders, in a mammal comprising measuring MC4-r gene expression in a patient sample.

25 33. The method of Claim 32 in which expression is measured by detecting mRNA transcripts of the MC4-r gene.

34. The method of Claim 32 in which expression is measured by detecting the MC4-r gene product.

30

35. A method for diagnosing body weight disorders in a mammal, comprising detecting a MC4-r gene mutation contained in the genome of the mammal.

35 36. The method of Claim 35 in which the mutation is located at nucleotide 137 of the MC4-r gene.

37. An isolated DNA consisting of an altered MC4-r sequence having a G at nucleotide 102.

38. An isolated DNA consisting of an altered MC4-r sequence 5 having a C at nucleotide 137.

39. An isolated DNA consisting of an altered MC4-r sequence having a T at nucleotide 112.

10 40. A nucleic acid probe complementary to human altered MC4-r gene sequences, wherein said nucleic acid probe hybridizes to a mutant MC4-r gene under conditions which prevent hybridizing of said nucleic acid probe to an MC4-r gene having a wild-type sequence.

15

41. The nucleic acid probe of Claim 40 wherein the mutant MC4-r gene has a G at the nucleotide corresponding to base number 102 in the MC4-r gene sequence.

20 42. The nucleic acid probe of Claim 40 wherein the mutant MC4-r gene has a C at the nucleotide corresponding to base number 137 in the MC4-r gene sequence.

43. The nucleic acid probe of Claim 40 wherein the mutant 25 MC4-r gene has a T at the nucleotide corresponding to base number 112 in the MC4-r gene sequence.

44. A method for identifying compounds that regulate body weight, comprising:

- 30 (a) contacting a test compound with a cell which expresses a mutant melanocortin 4-receptor, and
(b) determining whether the test compound activates the melanocortin 4-receptor,

in which test compounds that activate the melanocortin 4- 35 receptor are identified as compounds for inducing weight loss.

ECD 1 50

1

HC3 HSIQKKYLEG DFVFPVSSSS FLRTLLEPQL GSALLTANNA SCCLPSVQPT
 HC4 :MVNSTHRCM HTSLHLWNRS SYRLHS....
 HC2 (ACTH) :.....MKH
 HC1 (α-MSH) :.....MAV QGSQRRLGGS

I 100

51

HC3 LPNGSEHLOA PFFSNQSSSA FCEOVFIKPE IFLSLGIIVSL LENILVILAV
 HC4 ..NASESLGK GY....SDCG CYEQLFVSPE VFVTLGVISL LENILVIVAI
 HC2 (ACTH) IINSYENINN T'....ARMS DCPRVLPPEE IFFTISIVGV LENILVLLAV
 HC1 (α-MSH) LNSTPTAIPO LQLAANQTGA RCLEVSISDG LFLSLGLVSL VENALVVATI

CD 1 150

101

HC3 VRNGNLHSPH YFFICSLAVA DMLVSVSNAL ETIKIAIVHS DYLTFFEDQFI
 HC4 AKKNKHLHSPH YFFICSLAVA DMLVSVSNGS ETIITLLNS T.DTDAQSFT
 HC2 (ACTH) FIONGLOAPH YFFICSLATS DMLGSLYKIL ENILILRNH GYLKPROSFE
 HC1 (α-MSH) AKNRNLHSPH YCFICCLALS DLLVSGTNVL ETAVILLEA GALVARAAVL

CD 2 200

151

HC3 QHMDNIFDSH ICISLVASIC NLLAIAVDRY VTIFYALRYH SIHTVRKALT
 HC4 VNIDNVIDSV ICSSLLASIC SLLSIAVDRY FTIFYALOYH NIMTVKRVGI
 HC2 (ACTH) TTADDIISL FVLSILGSIF SLSVIAADRY ITIFHALRYH SITVTRRTVV
 HC1 (α-MSH) QQLDNVIDVI TCSSHLSSLC FLGAIAVDRY ISIFYALRYH SITVLPFRARQ

ECD 3 250

201

HC3 LIVAIWCCG VCGVVFIVYS ESKMVTVCLI THFFAHMLLH GTLYVIRFLF
 HC4 IISCINAACT VSGILFIYS DSSAVIICLI THFFHMLAH ASLYVIRFLH
 HC2 (ACTH) VLTIVITFCT GCGITMVIFS HKVPTVITFT SLFPLHLVFI LCLYVIRFLF
 HC1 (α-MSH) AVAAIWVASV VFSTLFIAYY DHVAVLLCLV VFFLAHLVLH AVLYVIRLAR

CD 3 300

251

HC3 ARLHKVRIAA LPPADGVAPQ QHSCHKGAVT ITILIGVFIF CHAPFFLHLV
 HC4 ARLHKVRIAV LPPGCAI..R OGARKGAVT LTILIGVFVV CHAPFFLHLI
 HC2 (ACTH) ARSHTRKIST LPR..... :..ARKGAVT LTILIGVFIF CHAPFFLHLV
 HC1 (α-MSH) ACOHAQGIAR LNKRO.RPVH QGFLKGAVT LTILIGIFFL CHGFFFLHLT

CD 4 350

301

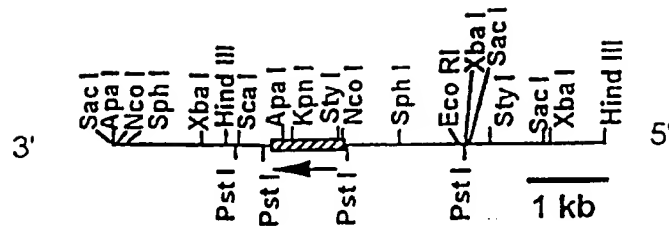
HC3 LIITCPTNPY CICYTAHFT YLVLMCHNSV IDPLTYAFRS LELRNTFREI
 HC4 FYISCOPNPY CVCFMHFNL YLILIMCHSI IDPLTYALRS QELRKTFFKEI
 HC2 (ACTH) LHTFCPSNPY CACVMSLFOV NGMLTMCHAV IDPFIYAFRS PELRDAFKKH
 HC1 (α-MSH) LIVLCPEHPT CGCIFKNFNL FLALIIICIAI IDPLTYAFHS QELRRTLKEV

351

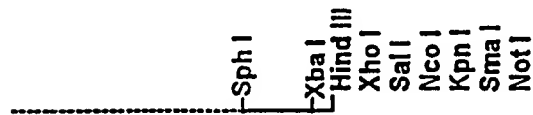
HC3 LCGCNGMNLG
 HC4 ICCYPLOGLC DLSSRY
 HC2 (ACTH) IFCSRYW
 HC1 (α-MSH) LTCSEW

Fig. 1

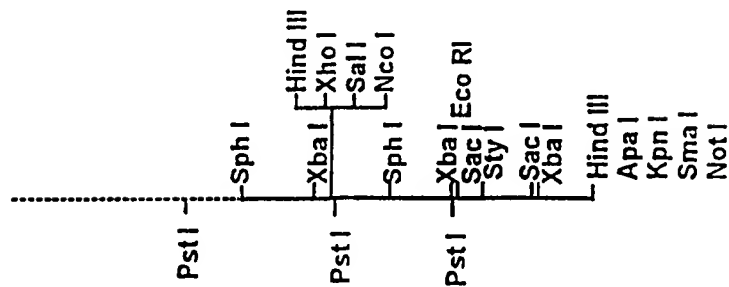
2 A) MC4-R locus



2 B) MC4-R KO 5'



2 C) MC4-R KO 5'3'



2 D) MC4-R KO 5'3' neo

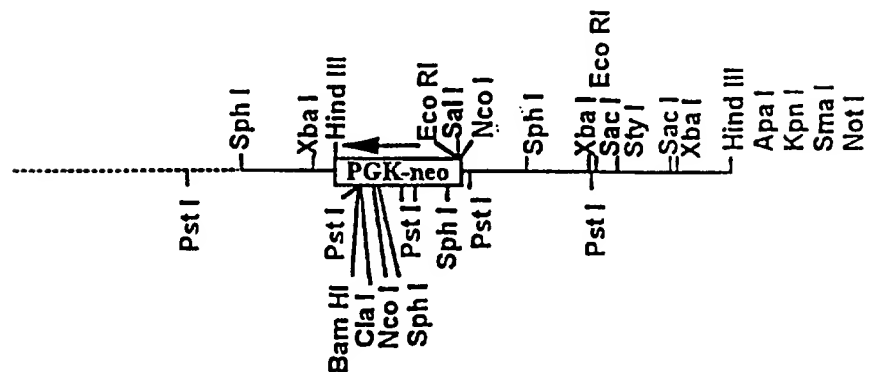
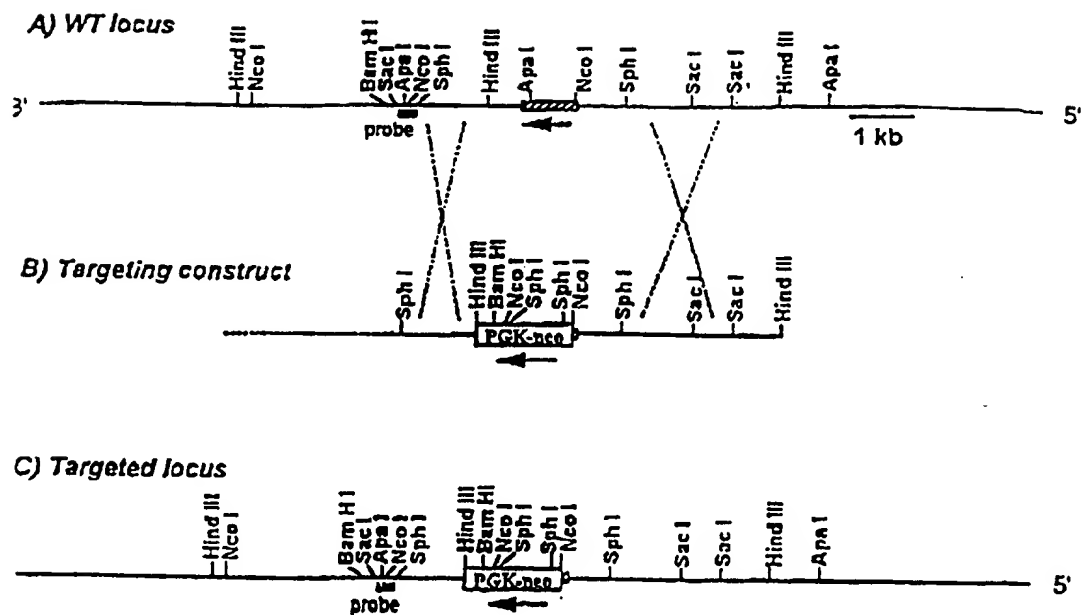


Fig. 2A - 2D



D) Expected restriction fragment sizes (kb)

Enzyme	WT	KO
Apa I	2.2	7.6
Bam HI	~17	2.1
Nco I	2.8	2.8
	2.6	2.6
		1.9
Kpn I	4	>>4
Eco RI	9.9	8.4

FIGS. 3A-3D

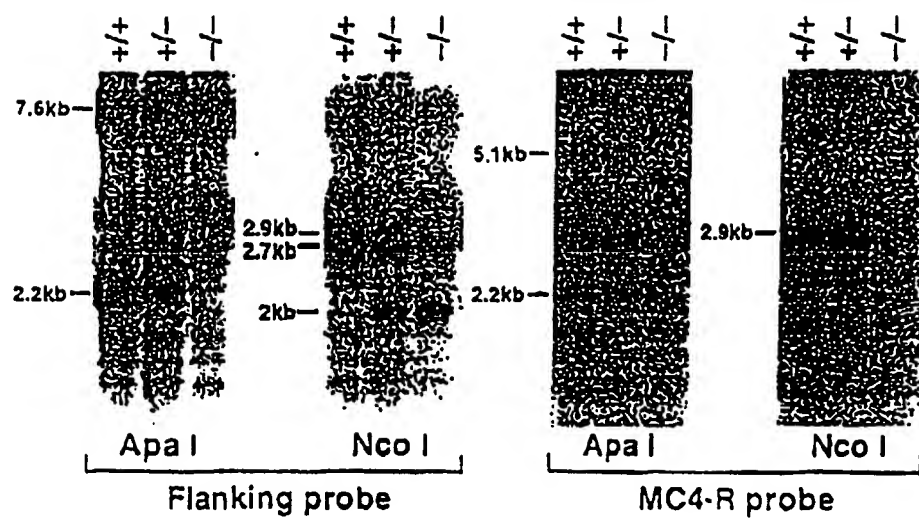
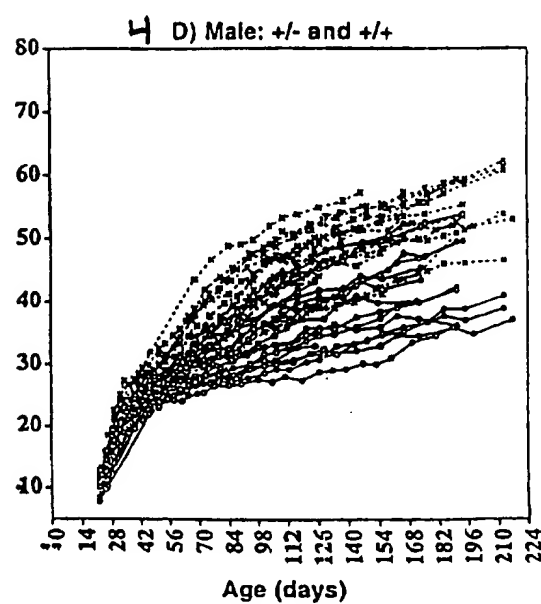
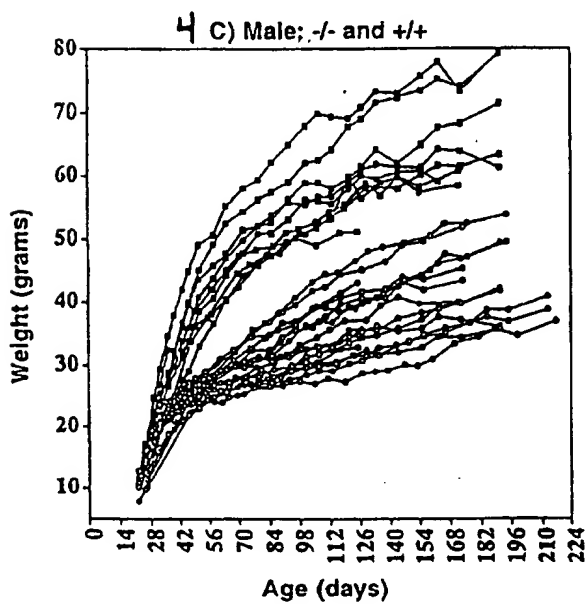
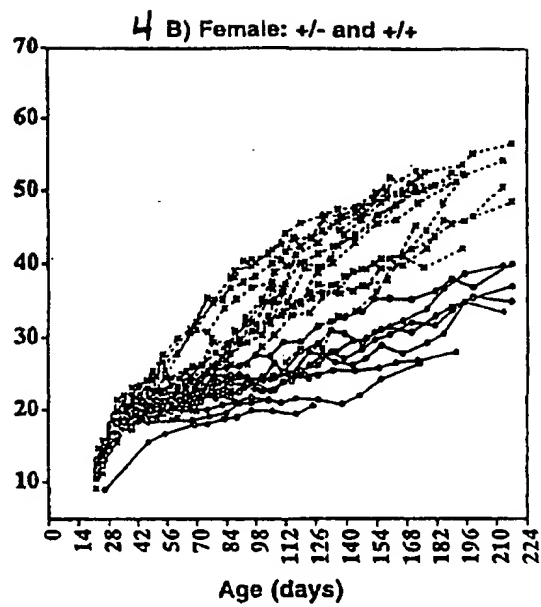
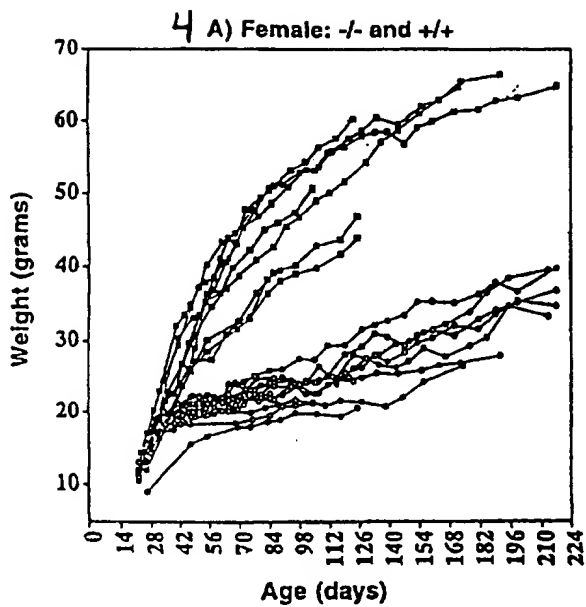


FIG. 3E



FIGS. 4A - 4D

ACC TTC CGA GAG GCA GCC GAT GTG AGC ATG TGC GCA CAG ATT CGT CTC CCA ATG -340
 GCA TGC CAG CTT CAA GCA AAA TTA TTT TGA ACA GAC TTG AAT GCA TAA GAT TAA -286
 AGT TAA AGC AGA AGT GAG AAC AAG AAA GCA AAG AGC AGA CTC TTT CAA CTG AGA -232
 ATG AAT ATT TTG AAG CCC AAG ATT TTA AAG TGA TGA TTA GAG TCG TAC CTA -178
 AAA GAG ACT AAA AAC TCC ATG TCA AGC TCT GGA CTT GTG ACA TTT ACT CAC AGC -124
 AGG CAT GGC AAT TTT AGC CTC ACA ACT TTC AGA CAG ATA AAG ACT TGG AGG AAA -70
 TAA CTG AGA CGA CTC CCT GAC CCA GGA GGT TAA ATC AAT TCA GGG GGA CAC TCG -16

 AAT TCT CCT GCC AGC ATG GTG AAC TCC ACC CAC CGT GGG ATG CAC ACT TCT CTG 39
 MET Val Asn Ser Thr His Arg Gly MET His Thr Ser Leu 13

 CAC CTC TGG AAC CGC AGC AGT TAC AGA CTG CAC AGC AAT GCC AGT GAG TCC CTT 93
 His Leu Trp Asn Arg Ser Ser Tyr Arg Leu His Ser Asn Ala Ser Glu Ser Leu 31

 GGA AAA GGC TAC TCT GAT GGA GGG TGC TAC GAG CAA CTT TTT GTG TCT CCT GAG 147
 Gly Lys Gly Tyr Ser Asp Gly Gly Cys Tyr Glu Gln Leu Phe Val Ser Pro Glu 49

 I
 GTG TTT GTG ACT CTG GGT GTC ATC AGC TTG TTG GAG AAT ATC TTA GTG ATT GTG 201
 Val Phe Val Thr Leu Gly Val Ile Ser Leu Leu Glu Asn Ile Leu Val Ile Val 67

 GCA ATA GCC AAG AAC AAG AAT CTG CAT TCA CCC ATG TAC TTT TTC ATC TGC ACC 255
 Ala Ile Ala Lys Asn Lys Asn Leu His Ser Pro MET Tyr Phe Phe Ile Cys Ser 85

 II
 TTG GCT GTG GCT GAT ATG CTG GTG AGC GTT TCA AAT GCA TCA GAA ACC ATT ATC 309
 Leu Ala Val Ala Asp MET Leu Val Ser Val Ser Asn Gly Ser Glu Thr Ile Ile 103
 Val Ser Val

 ATC ACC CTA TTA AAC AGT ACA GAT ACG GAT GCA CAG AGT TTC ACA GTG AAT ATT 363
 Ile Thr Leu Leu Asn Ser Thr Asp Thr Asp Ala Gln Ser Phe Thr Val Asn Ile 121

 III
 GAT AAT GTC ATT GAC TCG GTG ATC TGT AGC TCC TTG CTT GCA TCC ATT TGC AGC 417
 Asp Asn Val Ile Asp Ser Val Ile Cys Ser Ser Leu Leu Ala Ser Ile Cys Ser 139

 CTG CTT TCA ATT GCA GTG GAC AGG TAC TTT ACT ATC TTC TAT GCT CTC CAG TAC 471
 Leu Leu Ser Ile Ala Val Asp Arg Tyr Phe Thr Ile Phe Tyr Ala Leu Gln Tyr 157

 CAT AAC ATT ATG ACA GTT AAG CCG GTT GGG ATC AOC ATA AGT TGT ATC TGG GCA 525
 His Asn Ile MET Thr Val Lys Arg Val Gly Ile Ser Ile Ser Cys Ile Trp Ala 175
 Arg Ile

 IV
 GCT TGC ACG GTT TCA GGC ATT TTG TTC ATC ATT TAC TCA GAT AGT AGT GCT CTC 579
 Ala Cys Thr Val Ser Gly Ile Leu Phe Ile Ile Tyr Ser Asp Ser Ser Ala Val 193
 Val

 V
 ATC ATC TGC CTC ATC ACC AAT TTC TTC ACC ATG CTG GCT CTC ATG GCT TCT CTC 633
 Ile Ile Cys Leu Ile Thr MET Phe Phe Thr MET Leu Ala Leu MET Ala Ser Leu 211
 Val

 TAT GTC CAC ATG TTC CTG ATG GCC AGG CTT CAC ATT AAG AGG ATT GCT GTC CTC 687
 Tyr Val His MET Phe Leu MET Ala Arg Leu His Ile Tyr Arg Ile Ala Val Leu 229

 CCC GGC ACT GGT GCC ATC CCG CAA GGT GCC AAT ATG AAG GGA GCG ATT ACC TTG 741
 Pro Gly Thr Gly Ala Ile Arg Gln Gly Ala Asn MET Lys Gly Ala Ile Thr Leu 247
 Thr

 VI
 ACC ATC CTG ATT GGC GTC TTT GTT GTC TGC TGG GCC CCA TTC TTC CTC CAC TTA 795
 Thr Ile Leu Ile Gly Val Phe Val Val Cys Trp Ala Pro Phe Phe Leu His Leu 265

 ATA TTC TAC ATC TCT TGT CCT CAG AAT CCA TAT TGT GTG TGC TTC ATG TCT CAC 849
 Ile Phe Tyr Ile Ser Cys Pro Gln Asn Pro Tyr Cys Val Cys Phe MET Ser His 283
 Leu

 VII
 TTT AAC TTG TAT CTC ATA CTG ATC ATG TGT AAT TCA ATC ATC GAT CCT CTG ATT 903
 Phe Asn Leu Tyr Leu Ile Leu Ile MET Cys Asn Ser Ile Ile Asp Pro Leu Ile 301

 TAT GCA CTC CCG AGT CAA GAA CTG AGG AAA ACT TTC AAA CAG ATC ATC TGT TGC 957
 Tyr Ala Leu Arg Ser Gln Glu Leu Arg Lys Thr Phe Lys Glu Ile Ile Cys Cys 319

 TAT CCC CTG GGA GCC CTT TGT GAC TTG TCT AGC AGA TAT TAA ATG GGG ACA GAG 996
 Tyr Pro Leu Gly Gly Leu Cys Asp Leu Ser Ser Arg Tyr 332

 CAC GCA ATA TAG CAA CAT CCA TAA GAG ACT TTT TCA CTC TTA CCC TAC CTG AAT 1050
 ATT GTA CTT CTG CAA CAG CTT TCT CTT CCG TGT AGC GTA CTG CTT GAG ATA TCC 1108
 ATT GTG TAA ATT TAA GCC TAT GAT TTT TAA TGA GAA AAA ATG CCC AGT CTC TGT 1162
 ATT ATT TCC AAT GTC ATG CTA CTT TTT TGG CCA TAA AAT ATG AAT CTA TGT TAT 1216
 AGG TTG TAG GCA CTC TCG ATT TAC AAA AAG AAA AGT CCT TAT TAA AAG CTT 1267

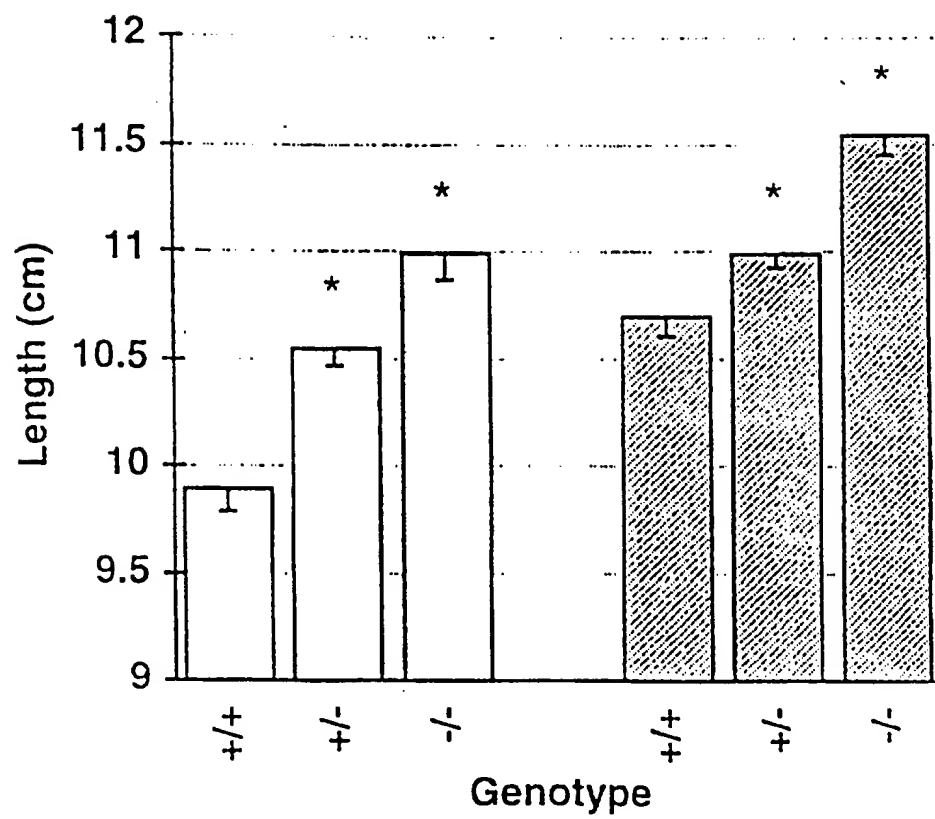


FIG. 6

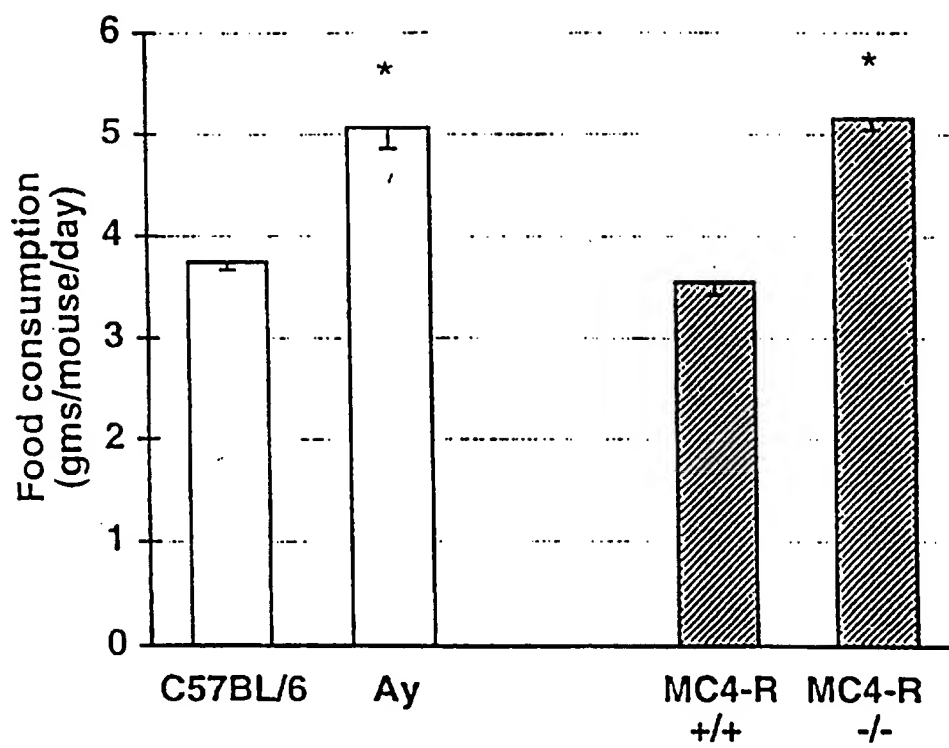
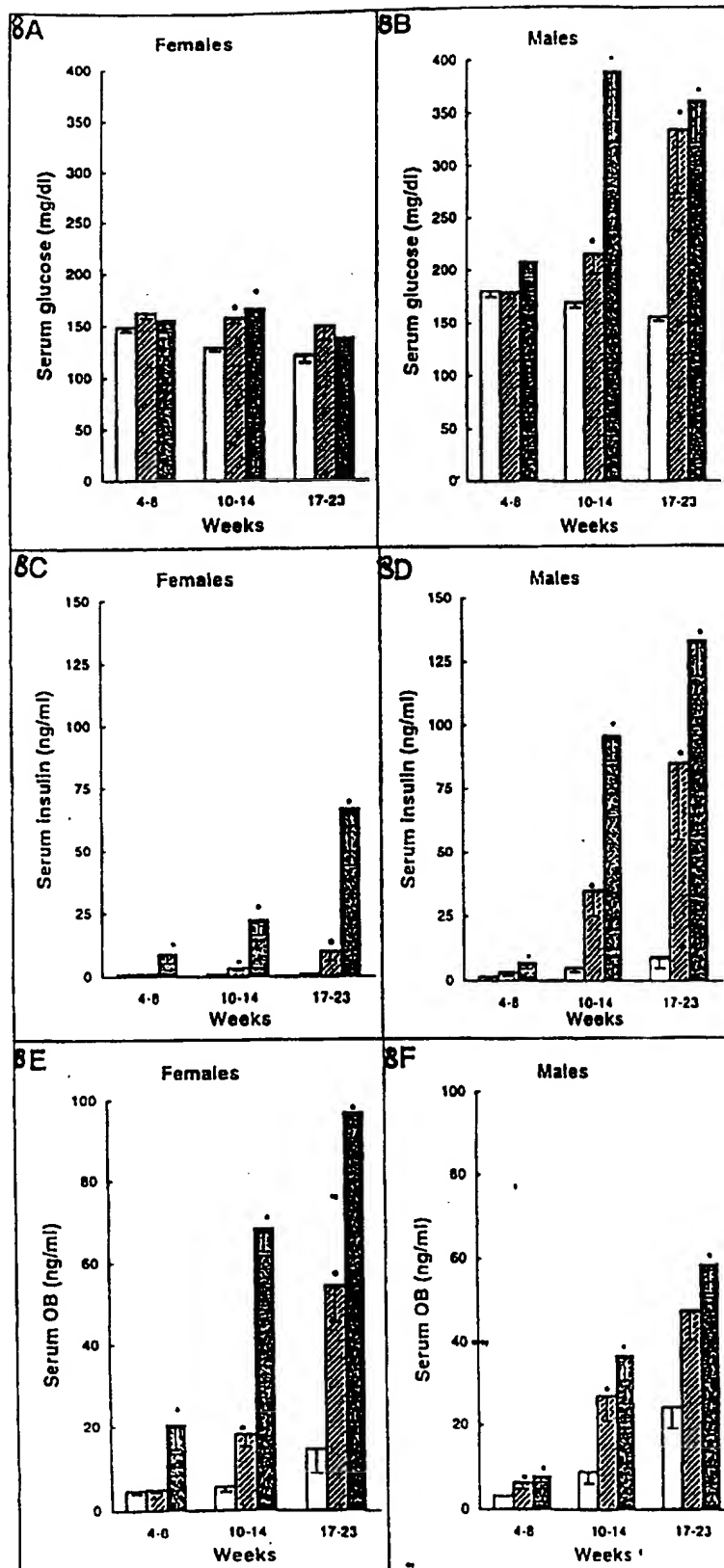


FIG. 7



FIGS 8A-8F

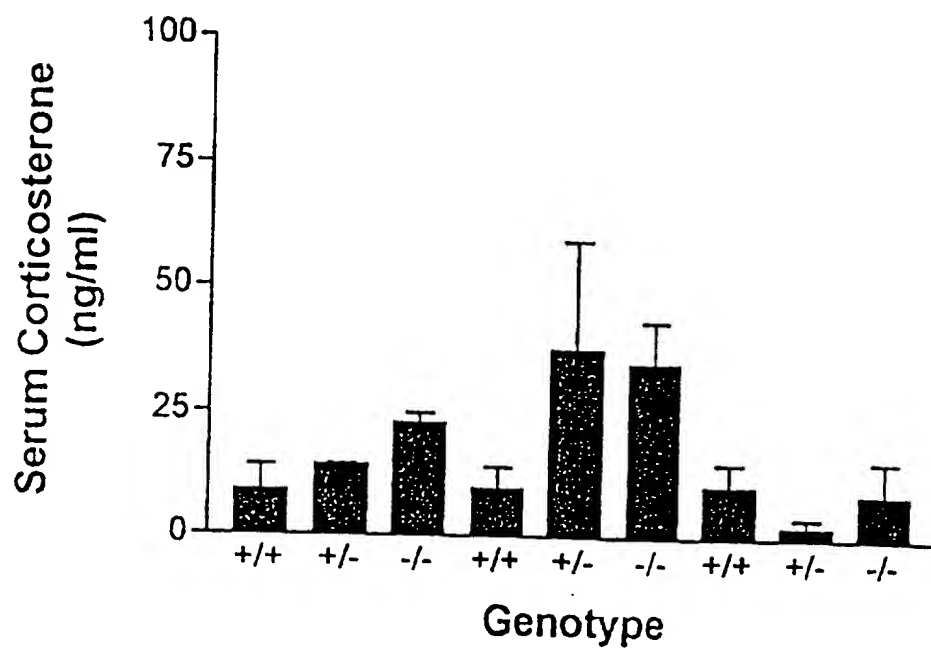
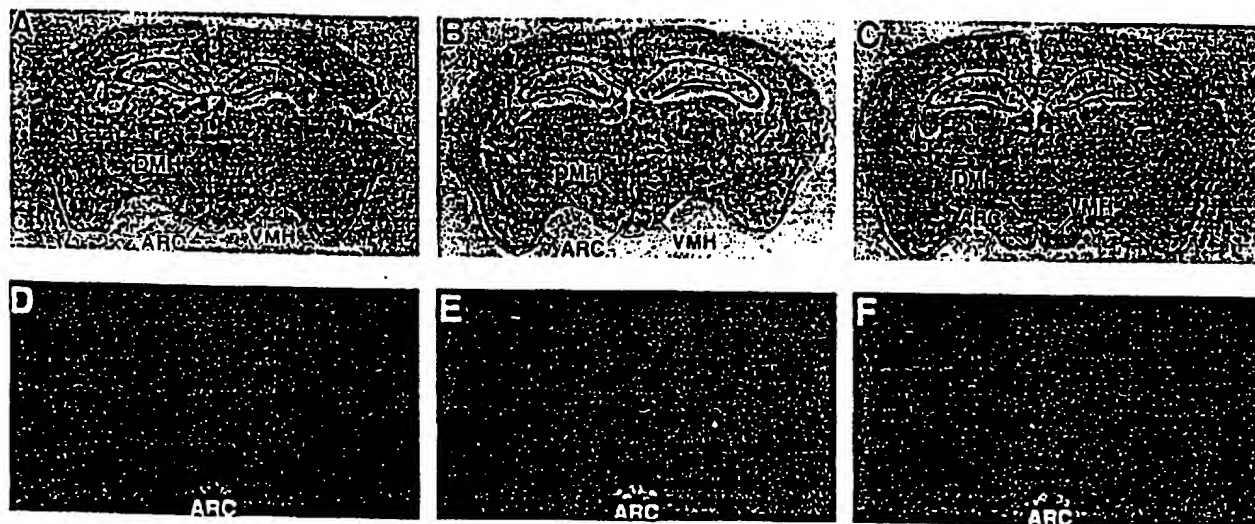


FIG. 9



FIGS. 10A - 10F

atg gtg aac tcc acc cac cgt ggg atg cac act tct ctg cac ctc tgg	48
Met Val Asn Ser Thr His Arg Gly Met His Thr Ser Leu His Leu Trp	
5 10 15	
aac cgc agc agt tac aga ctg cac agc aat gcc agt gag tcc ctt gga	96
Asn Arg Ser Ser Tyr Arg Leu His Ser Asn Ala Ser Glu Ser Leu Gly	
20 25 30	
aaa ggc tac tct gat gga ggg tgc tac gag caa ctt ttt gtc tct cct	144
Lys Gly Tyr Ser Asp Gly Gly Cys Tyr Glu Gln Leu Phe Val Ser Pro	
35 40 45	
gag gtg ttt gtg act ctg ggt gtc atc agc ttg ttg gag aat atc tta	192
Glu Val Phe Val Thr Leu Gly Val Ile Ser Leu Leu Glu Asn Ile Leu	
50 55 60	
gtg att gtg gca ata gcc aag aac aag aat ctg cat tca ccc atg tac	240
Val Ile Val Ala Ile Ala Lys Asn Lys Asn Leu His Ser Pro Met Tyr	
65 70 75 80	
ttt ttc atc tgc agc ttg gct gtg gct gat atg ctg gtg agc gtt tca	288
Phe Phe Ile Cys Ser Leu Ala Val Ala Asp Met Leu Val Ser Val Ser	
85 90 95	
aat gga tca gaa acc gtt atc atc acc cta tta aac agt aca gat acg	336
Asn Gly Ser Glu Thr Val Ile Ile Thr Leu Leu Asn Ser Thr Asp Thr	
100 105 110	
gat gca cag agt ttc aca gtg aat att gat aat gtc att gac tcg gtg	384
Asp Ala Gln Ser Phe Thr Val Asn Ile Asp Asn Val Ile Asp Ser Val	
115 120 125	
atc tgt agc tcc ttg ctt gca tcc act tgc agc ctg ctt tca att gca	432
Ile Cys Ser Ser Leu Leu Ala Ser Thr Cys Ser Leu Leu Ser Ile Ala	
130 135 140	
gtg gac agg tac ttt act atc ttc tat gct ctc cag tac cat aac att	480
Val Asp Arg Tyr Phe Thr Ile Phe Tyr Ala Leu Gln Tyr His Asn Ile	
145 150 155 160	
atg aca gtt aag cgg gtt ggg atc agc ata agt tgt atc tgg gca gct	528
Met Thr Val Lys Arg Val Gly Ile Ser Ile Ser Cys Ile Trp Ala Ala	
165 170 175	
tgc acg gtt tca ggc att ttg ttc atc att tac tca gat agt agt gct	576
Cys Thr Val Ser Gly Ile Leu Phe Ile Ile Tyr Ser Asp Ser Ser Ala	
180 185 190	
gtc atc atc tgc ctc atc acc atg ttc ttc acc atg ctg gct ctc atg	624

FIG. 11A

12/18

Val Ile Ile Cys Leu Ile Thr Met Phe Phe Thr Met Leu Ala Leu Met
 195 200 205

gct tct ctc tat gtc cac atg ttc ctg atg gcc agg ctt cac att aag 672
 Ala Ser Leu Tyr Val His Met Phe Leu Met Ala Arg Leu His Ile Lys
 210 215 220

agg att gct gtc ctc ccc ggc act ggt gcc atc cgc caa ggt gcc aat 720
 Arg Ile Ala Val Leu Pro Gly Thr Gly Ala Ile Arg Gln Gly Ala Asn
 225 230 235 240

atg aag gga gcg att acc ttg acc atc ctg att ggc gtc ttt gtt gtc 768
 Met Lys Gly Ala Ile Thr Leu Thr Ile Leu Ile Gly Val Phe Val Val
 245 250 255

tgc tgg gcc cca ttc ttc ctc cac tta ata ttc tac atc tct tgt cct 816
 Cys Trp Ala Pro Phe Phe Leu His Leu Ile Phe Tyr Ile Ser Cys Pro
 260 265 270

cag aat cca tat tgt gtg tgc ttc atg tct cac ttt aac ttg tat ctc 864
 Gln Asn Pro Tyr Cys Val Cys Phe Met Ser His Phe Asn Leu Tyr Leu
 275 280 285

ata ctg atc atg tgt aat tca atc atc gat cct ctg att tat gca ctc 912
 Ile Leu Ile Met Cys Asn Ser Ile Ile Asp Pro Leu Ile Tyr Ala Leu
 290 295 300

cgg agt caa gaa ctg agg aaa acc ttc aaa gag atc atc tgt tgc tat 960
 Arg Ser Gln Glu Leu Arg Lys Thr Phe Lys Glu Ile Ile Cys Cys Tyr
 305 310 315 320

ccc ctg gga ggc ctt tgt gac ttg tct agc aga tat taa 999
 Pro Leu Gly Gly Leu Cys Asp Leu Ser Ser Arg Tyr Stop
 325 330

FIG. 11B

atg gtg aac tcc acc cac cgt ggg atg cac act tct ctg cac ctc tgg	48
Met Val Asn Ser Thr His Arg Gly Met His Thr Ser Leu His Leu Trp	
5 10 15	
aac cgc agc agt tac aga ctg cac agc aat gcc agt gag tcc ctt gga	96
Asn Arg Ser Ser Tyr Arg Leu His Ser Asn Ala Ser Glu Ser Leu Gly	
20 25 30	
aaa ggc tac tct gat gga ggg tgc tac gag caa ctt ttt gtc tct cct	144
Lys Gly Tyr Ser Asp Gly Gly Cys Tyr Glu Gln Leu Phe Val Ser Pro	
35 40 45	
gag gtg ttt gtg act ctg ggt gtc atc agc ttg ttg gag aat atc tta	192
Glu Val Phe Val Thr Leu Gly Val Ile Ser Leu Leu Glu Asn Ile Leu	
50 55 60	
gtg att gtg gca ata gcc aag aac aag aat ctg cat tca ccc atg tac	240
Val Ile Val Ala Ile Ala Lys Asn Lys Asn Leu His Ser Pro Met Tyr	
65 70 75 80	
ttt ttc atc tgc agc ttg gct gtg gct gat atg ctg gtg agc gtt tca	288
Phe Phe Ile Cys Ser Leu Ala Val Ala Asp Met Leu Val Ser Val Ser	
85 90 95	
aat gga tca gaa acc att atc atc acc cta tta aac agt aca gat acg	336
Asn Gly Ser Glu Thr Ile Ile Ile Thr Leu Leu Asn Ser Thr Asp Thr	
100 105 110	
gat gca cag agt ttc aca gtg aat att gat aat gtc att gac tcg gtg	384
Asp Ala Gln Ser Phe Thr Val Asn Ile Asp Asn Val Ile Asp Ser Val	
115 120 125	
atc tgt agc tcc ttg ctt gca tcc att tgc agc ctg ctt tca att gca	432
Ile Cys Ser Ser Leu Leu Ala Ser Ile Cys Ser Leu Leu Ser Ile Ala	
130 135 140	
gtg gac agg tac ttt act atc ttc tat gct ctc cag tac cat aac att	480
Val Asp Arg Tyr Phe Thr Ile Phe Tyr Ala Leu Gln Tyr His Asn Ile	
145 150 155 160	
atg aca gtt aag cgg gtt ggg atc agc ata agt tgt atc tgg gca gct	528
Met Thr Val Lys Arg Val Gly Ile Ser Ile Ser Cys Ile Trp Ala Ala	
165 170 175	
tgc acg gtt tca ggc att ttg ttc atc att tac tca gat agt agt gct	576
Cys Thr Val Ser Gly Ile Leu Phe Ile Ile Tyr Ser Asp Ser Ser Ala	
180 185 190	
gtc atc atc tgc ctc atc acc atg ttc ttc acc atg ctg gct ctc atg	624

FIG. 12A

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Val	Ile	Ile	Cys	Leu	Ile	Thr	Met	Phe	Phe	Thr	Met	Leu	Ala	Leu	Met		
	195						200					205					
gct	tct	ctc	tat	gtc	cac	atg	ttc	ctg	atg	gcc	agg	ctt	cac	att	aag	672	
Ala	Ser	Leu	Tyr	Val	His	Met	Phe	Leu	Met	Ala	Arg	Leu	His	Ile	Lys		
	210					215					220						
agg	att	gct	gtc	ctc	ccc	ggc	act	ggt	gcc	atc	cgc	caa	ggt	gcc	aat	720	
Arg	Ile	Ala	Val	Leu	Pro	Gly	Thr	Gly	Ala	Ile	Arg	Gln	Gly	Ala	Asn		
225					230					235					240		
atg	aag	gga	gcg	att	acc	ttg	acc	atc	ctg	att	ggc	gtc	ttt	gtt	gtc	768	
Met	Lys	Gly	Ala	Ile	Thr	Leu	Thr	Ile	Leu	Ile	Gly	Val	Phe	Val	Val		
				245					250					255			
tgc	tgg	gcc	cca	ttc	ttc	ctc	cac	tta	ata	ttc	tac	atc	tct	tgt	cct	816	
Cys	Trp	Ala	Pro	Phe	Phe	Leu	His	Leu	Ile	Phe	Tyr	Ile	Ser	Cys	Pro		
			260					265					270				
cag	aat	cca	tat	tgt	gtg	tgc	ttc	atg	tct	cac	ttt	aac	ttg	tat	ctc	864	
Gln	Asn	Pro	Tyr	Cys	Val	Cys	Phe	Met	Ser	His	Phe	Asn	Leu	Tyr	Leu		
		275						280				285					
ata	ctg	atc	atg	tgt	aat	tca	atc	atc	gat	cct	ctg	att	tat	gca	ctc	912	
Ile	Leu	Ile	Met	Cys	Asn	Ser	Ile	Ile	Asp	Pro	Leu	Ile	Tyr	Ala	Leu		
	290					295					300						
cgg	agt	caa	gaa	ctg	agg	aaa	acc	ttc	aaa	gag	atc	atc	tgt	tgc	tat	960	
Arg	Ser	Gln	Glu	Leu	Arg	Lys	Thr	Phe	Lys	Glu	Ile	Ile	Cys	Cys	Tyr		
305					310					315					320		
ccc	ctg	gga	ggc	ctt	tgt	gac	ttg	tct	agc	aga	tat	taa				999	
Pro	Leu	Gly	Gly	Leu	Cys	Asp	Leu	Ser	Ser	Arg	Tyr	Stop					
				325					330								

FIG. 12B

Val Ile Ile Cys Leu Ile Thr Met Phe Phe Thr Met Leu Ala Leu Met
 195 200 205

gct tct ctc tat gtc cac atg ttc ctg atg gcc agg ctt cac att aag 672
 Ala Ser Leu Tyr Val His Met Phe Leu Met Ala Arg Leu His Ile Lys
 210 215 220

agg att gct gtc ctc ccc ggc act ggt gcc atc cgc caa ggt gcc aat 720
 Arg Ile Ala Val Leu Pro Gly Thr Gly Ala Ile Arg Gln Gly Ala Asn
 225 230 235 240

atg aag gga gcg att acc ttg acc atc ctg att ggc gtc ttt gtt gtc 768
 Met Lys Gly Ala Ile Thr Leu Thr Ile Leu Ile Gly Val Phe Val Val
 245 250 255

tgc tgg gcc cca ttc ttc ctc cac tta ata ttc tac atc tct tgt cct 816
 Cys Trp Ala Pro Phe Phe Leu His Leu Ile Phe Tyr Ile Ser Cys Pro
 260 265 270

cag aat cca tat tgt gtg tgc ttc atg tct cac ttt aac ttg tat ctc 864
 Gln Asn Pro Tyr Cys Val Cys Phe Met Ser His Phe Asn Leu Tyr Leu
 275 280 285

ata ctg atc atg tgt aat tca atc atc gat cct ctg att tat gca ctc 912
 Ile Leu Ile Met Cys Asn Ser Ile Ile Asp Pro Leu Ile Tyr Ala Leu
 290 295 300

cgg agt caa gaa ctg agg aaa acc ttc aaa gag atc atc tgt tgc tat 960
 Arg Ser Gln Glu Leu Arg Lys Thr Phe Lys Glu Ile Ile Cys Cys Tyr
 305 310 315 320

ccc ctg gga ggc ctt tgt gac ttg tct agc aga tat taa 999
 Pro Leu Gly Gly Leu Cys Asp Leu Ser Ser Arg Tyr Stop
 325 330

FIG. 13B

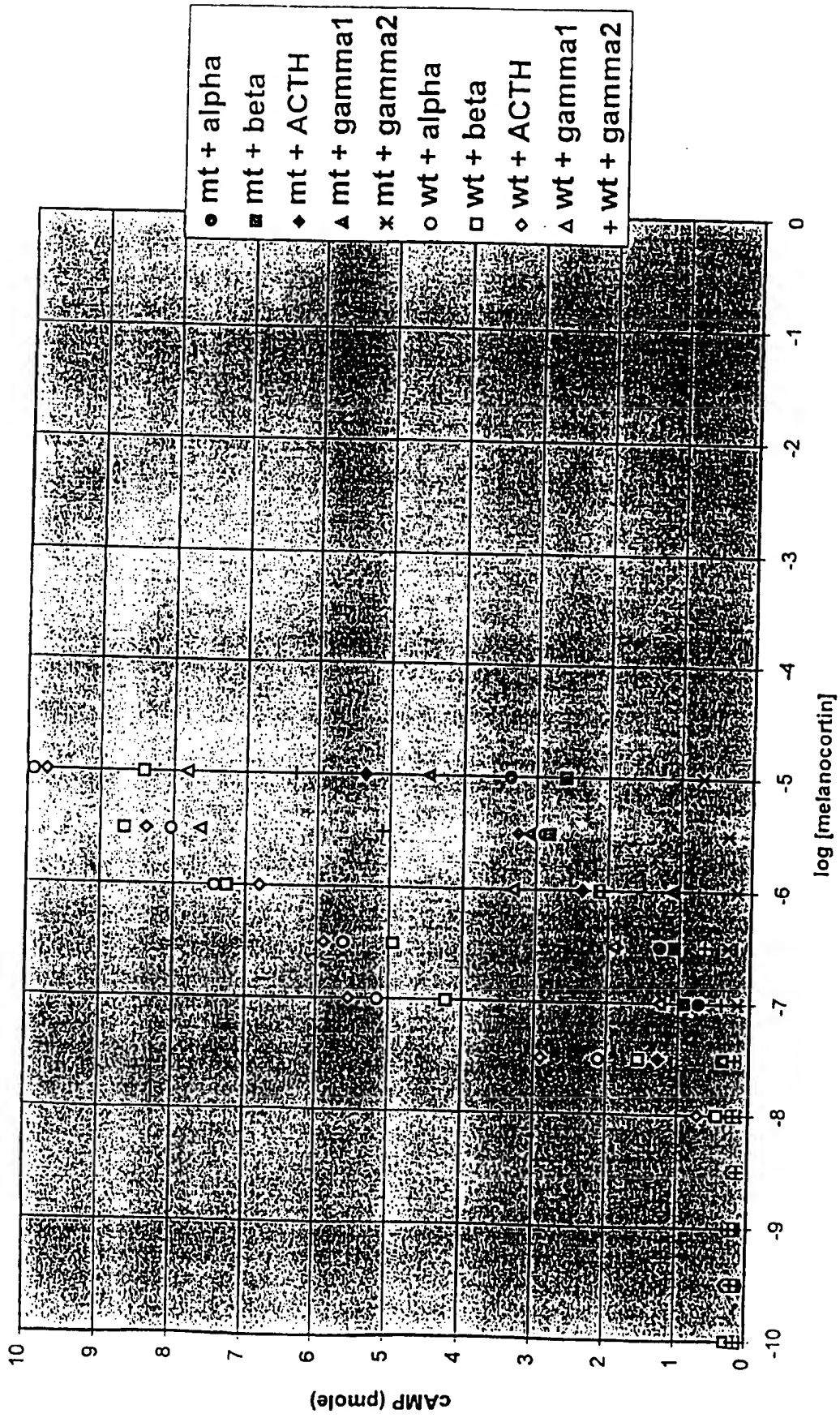


FIG. 14

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US97/09969

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) : Please See Extra Sheet.

US CL : Please See Extra Sheet.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 424/143.1, 145.1; 435/6, 7.1, 8, 346; 514/2, 44; 530/312, 399; 536/23.5, 24.5

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS; STN medline, embase, biosis, scisearch

TERMS: melanocortin, receptor

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	LU, D. et al. Agouti protein is an antagonist of the melanocyte-stimulating-hormone receptor. Nature, 27 October 1994, Vol. 371, pages 799-802, see entire document.	2-3, 6-10 --- 1, 4-5, 11, 13-14, 17, 19, 23, 25, 31
Y	ALBANESE, C. et al. Development of a bioassay for FSH using a recombinant human FSH receptor and a cAMP responsive luciferase reporter gene. Molec. Cell. Endocrinol. February 1994, Vol. 101, pages 211-219, see entire document.	4-5, 11, 31

☒ Further documents are listed in the continuation of Box C.
 ☐ See patent family annex.

* Special categories of cited documents:	*T	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
A document defining the general state of the art which is not considered to be of particular relevance	*X*	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
E earlier document published on or after the international filing date	*Y*	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
L document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	*Z*	document member of the same patent family
O document referring to an oral disclosure, use, exhibition or other means		
P document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search

06 AUGUST 1997

Date of mailing of the international search report

10 SEP 1997

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US97/09969

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	ALVARO, J.D. Cloning of the rat melanocortin 4 receptor in brain and its regulation by opiates. Diss. Abstracts Int. February 1996. Vol. 56, No. 8, page 4165-B, especially DA9541392, see entire abstract.	12
Y	MAURI, A. et al. Melanocortins and opioids modulate early postnatal growth in rats. Regulatory Peptides. July 1995, Vol. 59, pages 59-66, see entire document.	12
Y	ADAN, R.A.H. et al. Identification of antagonists for melanocortin MC3, MC4 and MC5 receptors. Eur. J. Pharmacol. 1994, Vol. 269, pages 331-337, see entire document.	1-12
A,P	KESTERSON, R.A. et al. Induction of neuropeptide Y gene expression in the dorsal medial hypothalamic nucleus in two models of the agouti obesity syndrome. Molec. Endocrinol. May 1997, Vol. 11, No. 5, pages 630-637, see entire document.	1-44
A,P	HUSZAR, D. et al. Targeted disruption of the melanocortin-4 receptor expression results in obesity in mice. Cell. 10 January 1997, Vol. 88, No. 1, pages 131-141, see entire document.	1-44

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US97/09969

CLASSIFICATION OF SUBJECT MATTER:

PC (6):
A61K 38/16, 39/395, 48/00; C07H 21/04; C12N 15/11; C12Q 1/68; G01N 33/53; C12Q 1/25, 1/66, 1/68

A. CLASSIFICATION OF SUBJECT MATTER:

US CL :
424/143.1, 145.1; 435/6, 7.1, 8, 346; 514/2, 44; 530/312, 399; 536/23.5, 24.5